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Col Paul G. Atkinson, Jr., Commander, Aerospace Research Laboratories (ARL) and Dr. Hans J. P. von Ohain, Chief Scientist, ARL discuss wedge-shaped hypersonic model mounted for testing in ARL's 20" hypersonic wind tunnel. This facility is typical of the advanced equipment installed at ARL to support in-house research in the engineering sciences.

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JACOB SEIDEN *Editor*

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A BRIEF HISTORY OF ARL's 20 YEARS OF PROGRESS

LOUIS G. KEHRT
Directorate of Plans and Analysis, ARL

The organization which we know today as the Aerospace Research Laboratories (ARL) began life as the brainchild of the late Dr. Theodore von Karman. In 1948, as Chairman of the Scientific Advisory Board, USAF, Dr. von Karman recommended that a research office be formed in the Wright-Patterson area as a means of more effectively using highly qualified scientific personnel. The scientists of this research office were to carry on research of a fundamental nature, act as scientific consultants and advisors to the other Air Force laboratories, and participate in the evaluation of research accomplished in universities and other research agencies. Dr. von Karman stressed that these people should be carefully selected on the basis of personal scientific achievement and publication of successful works rather than on seniority of service. The fundamental concepts he formulated have continually guided ARL's evolution and growth.

These early efforts to provide an independent research activity within the Air Force resulted in the introduction, in February 1948, of an Applied Research Section in the Engineering Division, Directorate of R&D, Air Materiel Command (AMC) at Wright-Patterson AFB. Colonel Leighton I. Davis was Chief of the Section, which had the responsibility for a variety of functions relating to basic research. In February 1949, the Section was redesignated the Office of Air Research, still with the Directorate of R&D, AMC. Under Col Frank J. Seiler, who became Chief in December 1949, the Office continued to perform and sponsor basic research, but in-house laboratory facilities were meagre. After the Air Research and Development Command (ARDC) was established on 2 April 1951, the research facilities at Wright Field were expanded to conduct basic research on a Laboratory level.

In March 1951, Colonel Leslie B. Williams became Chief of the Office, and on 20 April 1951 it was renamed the Flight Research Laboratory, and placed under the Wright Air Development Center (WADC), ARDC. As a consequence, the newly named Laboratory reoriented its program to concentrate on applied-research problems of specific interest to WADC. Additional mission activities were added, specifically in the areas of computation and simulation. The number of scientific personnel assigned to the Laboratory was doubled. Budget authorizations were increased threefold, and the first official request for a new research facility was prepared. In the meantime, various temporary buildings located in Area "B" and Area "C" were used to conduct research experiments and to monitor contract research. In May 1953, the Flight Research Laboratory was renamed the Aeronautical Research Laboratory, still under WADC, and the traditional ARL monogram was created.

In July 1955, the command of the Aeronautical Research Laboratory passed to Colonel Aldro I. Lingard who reorganized the Laboratory to reflect its widened scope of mission responsibilities. Research being conducted in this country on nuclear weapons brought increased Laboratory responsibilities in this field. To this end, in 1956, the Physics Research Branch of ARL was split into two branches: the Engineering Physics Research Branch, whose mission was to perform research in such areas as electron physics, plasma physics, and space physics; and the Modern Physics Research Branch, which was organized to conduct research in nuclear and solid-state physics and gravitational field theory. Also, additional emphasis was placed upon obtaining large-scale electronic computing machinery for solving many critical problems slowing the development of Air Force weapon systems.

With the advent of satellite technology, Air Force R&D emphasis shifted from the operation of manned flight vehicles within the earth's atmosphere to the development of intercontinental ballistic missiles and artificial earth satellites, and research performed by the personnel of the Aeronautical Research Laboratory moved forward to an active search for space-related knowledge and for solutions to problems anticipated in space travel. Under the direction of Colonel Nathan L. Krisberg, who was assigned as Chief of ARL in July 1956, the Laboratory realigned its program so as to concentrate on the important "space-flight" requirements. This was accomplished through the consolidation and termination of many tasks, which permitted the streamlining of the over-all Laboratory program. At the

same time, there was initiated a long-term policy of maintaining a stabilized research effort. This, in turn, facilitated the establishment of a firm scientific foundation upon which to build the strong technological base needed to insure the timely development of advanced weapon systems. During this period, the construction of Building 450 was completed, with dedication by Lt Gen James H. Doolittle (AFRes) on 2 May 1958. This new research facility was named the Aeronautical Research Laboratory Physical Sciences Building. Inscribed on its dedicatory plaque were these significant words by the late General H. H. Arnold, "Any Air Force which does not keep its doctrine ahead of its equipment, and its visions far into the future can only delude the nation into a false sense of security." Thus, ARL entered the second decade of its existence in this long-awaited new research facility, in an atmosphere free from the pressures of administrative paper work and developmental demands, and conducive to the conduct of untrammeled scientific research.

Under Colonel Eugene C. Mallary as Chief (then later as Director), the period from May 1958 through August 1961 was one of relatively rapid change as the move toward increasingly basic-research programs was pursued. Space-related problems were de-emphasized since they were considered as being more appropriate to the "space mission" assigned to the newly formed National Aeronautics and Space Administration (NASA). Also, in August 1959, ARL's Engineering Analysis Division, which had been set up in January 1958, was removed from ARL and established as a separate entity. This action broke off the organizations concerned primarily with basic research in the physical sciences from those oriented toward developmental efforts in computer technology and systems synthesis. It also resulted in a 25% decrease in manpower and a 10% budget reduction, primarily in the research contract program.

In January 1960 the two physics branches, which had remained unchanged since 1956, were restructured so as to form three separate physics branches. In addition, effective 1 April 1960, the Aeronautical Research Laboratory was transferred from the Wright Air Development Center to its new parent organization, the Air Force Research Division, a newly formed research-oriented component of ARDC. In August 1960, portions of ARL's Fluid Dynamics Research Branch were combined with ARL's Mechanics Research Branch to form a new element, the Thermomechanics Research Branch. And, in January 1961, another portion of the Fluid Dynamics Research Branch was removed to form the Hypersonic Research Branch.

On 1 April 1961, the Air Force Research Division (including ARL as one of its components) was separated from ARDC and organized as the Office of Aerospace Research, an independent operating agency of the Air Force with headquarters in Washington, D.C. This act completed the separation of basic research from developmental work, initiated a year earlier, and contributed significantly to the strengthening of Air Force basic research. It also marked the single most important step toward the full realization of Dr. von Karman's earlier dreams of a real Air Force basic-research capability.

April 1961 also witnessed the assignment of Colonel Robert E. Fontana to ARL. In September 1961 he became Director, and in April 1962 his title was changed to "Commander" of the "Aeronautical Research Laboratories," pursuant to the March 1962 Hq OAR Special Order which pluralized ARL and designated each research "branch" to be a "laboratory." On 1 July 1963, ARL's name was changed once more, to its present "Aerospace Research Laboratories." This latest name change marked official recognition of the fact that continued Air Force operational superiority requires active fundamental research programs in both the atmosphere and near-space area. Accordingly, Colonel Fontana's organization experienced a gradual shifting of emphasis from basic research in the physical sciences towards increasing relevance to Air Force needs. At the same time, programs in the engineering sciences were strengthened. During this same period, much was done to further improve the research environment. One important factor was a change in OAR management policies which permitted resources to be allocated to ARL in a lump sum, with the ARL Commander having the authority to shift monies between accounts (excepting for the payroll), as required. An even more important achievement, from the researchers' viewpoint, was a sharp improvement in the responsiveness of the supply and procurement systems.

Following the 1960-61 fiscal-year period, which represented a low point in ARL's resources, manpower grew steadily until, in 1964, it had returned to the 1959 level (i.e., prior to the loss of the Engineering Analysis Division). The budget followed a similar trend and leveled off in 1966 at a 50-percent gain compared to the 1960 low. This represented a doubling of the budget allocation for direct support of in-house research, and a level funding, essentially, of contract research. Since the 1964-66 highs, these resources have experienced only minor fluctuations. In order to provide space for the increasingly emphasized in-house research efforts, the ARL facilities have been augmented by additional small buildings, converted warehouse space, and portable office units. This has resulted in a facility growth of about 50 percent over the past decade.

Colonel Paul G. Atkinson, Jr., present ARL Commander, was originally assigned to the organization in July 1965 as Deputy Commander. Since taking over command in June 1966, there has been increased emphasis on maintaining a strong relevance of ARL research programs to present and future Air Force needs, particularly in the light of the demands of our involvement in Southeast Asia. Efforts have been increased to bring more visibility into the relevance of ARL's fundamental research, and to accelerate the incorporation of information on research results and application concepts into technology. A certain realignment of research programs has also been effected in order to more efficiently achieve these goals. In August 1966, part of the Thermomechanics Research Laboratory was restructured to form the Energetics Research Laboratory. This gave ARL its current organization of 10 laboratories. Research in the area of plasma diagnostics and electric-arc

discharges has gradually been reoriented to provide an increasing emphasis on higher temperatures and pressures. Also, an independent interdisciplinary working group has been formed to study high-energy plasma phenomena relevant to fusion. In addition, the long-standing policy that contractual research efforts should directly support and extend in-house research has been more aggressively pursued. Some large contract programs have been reduced, and the level of funds applied to the direct support of in-house research has been raised.

The continuing efforts over the years to cultivate the young research laboratory have succeeded in developing a strong competence in selected areas of the physical and engineering sciences. The resulting research programs have yielded an impressive compilation of papers published in the scientific literature, and have led to many applications highly important to the Air Force. Typical examples of some earlier efforts are bluff bomb shapes which have led to bombs of greatly improved ballistics; magnetic materials like ferrites which are now in common use in computer memory cores; nose-wheel-shimmy theory and alleviation methods which are now used in the design of aircraft; cadmium-sulfide solar cells now being readied for operational use; aerodynamic theories of re-entry bodies; and others. In more recent years, new concepts have evolved. For example, improved inertial separators resulting from fundamental research on swirl flows have been demonstrated for the Army as potential dust separators for turbine air intakes; colloid core reactors appear to have considerable promise as future propulsion and power sources for the space environment; thrust augmentation offers promise for both V/STOL (Vertical/Short Takeoff and Landing) and range extension; perchlorocarbons provide a new class of chemical compounds of great potential as polymers, lubricants, and high-temperature materials; night-vision techniques, both isocon low-light-level television tubes and infrared devices, offer a significant potential; blunt-trailing-edge-bladed supersonic compressors offer improved efficiency for higher-speed aircraft; metal chelate chemistry is important in analysis, chemical separation, and biochemical application; and there are many others.

In retrospect it can be seen that ARL's history may be logically divided into two quite dissimilar decades. The earlier period from 1948 through 1958 was a time of inception, evolution, and struggle for survival. The second decade, on the other hand, has been a period of relative stability, progress and achievement. ARL and its current parent organization, the Office of Aerospace Research, have demonstrated the value of Air Force-oriented fundamental research. Indeed, ARL has been recognized as a pioneer and a leader in various research areas, and provides the direct coupling so vital for the solution of Air Force R&D problems. The main mission and value of the Aerospace Research Laboratories, however, are to continuously prime the reservoir of fundamental knowledge from which all new technology flows. In so doing, ARL continues to fulfill its charge to assist the Air Force to "keep its doctrines ahead of its equipment, and its visions far into the future."

ADDRESS BY THE HONORABLE ALEXANDER H. FLAX

*Assistant Secretary of the Air Force Research & Development**

It is a great pleasure and privilege to be here to help celebrate the 20th anniversary of the Aerospace Research Laboratories. The theme of this celebration is "20 Years of Progress," and these have indeed been 20 years of progress in science and technology. But progress means change—change not just in the abstract world of research or even in the practical world of development, but in the national, social and economic environment in which the research is conducted. As our research and development activities have come to consume increasing shares of our national resources, the interaction with the national, social and economic environment has come to be of increasing importance; and it is to this subject that I would like to devote my remarks this evening, particularly as we are concerned with defense research and development.

We are now well along in what has been called the "Scientific Revolution." Whereas the older Industrial Revolution had its origins mainly in the empirical development of the arts and crafts, the Scientific Revolution depends upon the organized and systematic pursuit of research and development.

By speaking of the systematic and organized pursuit of scientific research I do not of course mean to imply that it is possible to schedule so-called "breakthroughs" in science and technology—although "breakthrough" is these days a much overworked word. However, I do mean that the over-all rate of progress in given fields can, in a major degree, be controlled by influencing the rate of allocation of material and human resources to given fields. At one time it was believed, and it was probably largely true, that progress in science and technology was entirely dependent on random factors—the rare-chance triple collision of an individual genius, the problem in the form of a need for a major step forward, and the right idea. But today it is realized that, in the long range, society can influence the population of genius, needs and ideas, not only in science as a whole, but in particular fields of science. Further, we recognize that the over-all level of activity in science and technology has the character of a thermodynamic temperature which influences the absolute probability of such triple collisions which are favorable to scientific progress.

The changes wrought by technological advances and the suddenness with which these changes occur shake the very foundations of organizations, institutions and societies, military and civilian alike. There is much yet to be learned about how to deal with these nontechnical problems of technological progress. Many of you have seen such changes in your lifetime: the impact of air transportation on railroads domestically, and on international commerce; political affairs and relationships among people; the effects of air power on military operations, and the effects of ballistic missiles on the conduct of international affairs; the influence of automobiles on the structure of urban and suburban communities; the influence of radio and television on our cultural life. You can all easily add to this list.

**This Address was given on the occasion of the 20th Anniversary Banquet at ARL, WPAFB, Ohio, on 9 May 1968.*

National expenditures for research and development, and test and evaluation now stand at about $22 billion, or 3 percent of the gross national product. About three quarters of this effort is supported by the Federal government. This is not a very large percentage of the gross national product. But it is a large sum of money, and the Federally supported segment is a significant percentage of the Federal budget—about 16 percent. I think we often tend to forget that, in our free society, the aim is to divert as much as possible of the gross national product into private rather than public hands. Therefore, reckoning the size of our Federally supported research and development program in terms of the gross national product has tended to obscure the key fact that research and development now take a substantial fraction of all the funds that the American public, through its elected representatives, diverts from the private sector of the economy.

During the past 10 years we have been through a period of highly accelerated growth in which the initiation of a massive space program, added to a rising curve of cost for the development and acquisition of ballistic missiles, has resulted in RDT&E growth rates as high as 20 percent per year. Growth in the Federal support of basic research has been even more dramatic, since funds for this purpose, from 1956 to 1966, have increased tenfold. Some people have tended to think of this maximum achieved growth rate as ordained to lay on a monotonically increasing curve, or at least a nondecreasing curve, so that growth and even the rate of growth of research and development would be destined to continue indefinitely. I am sure that it will not tax your mathematical powers to recall the laws of compound interest or geometric progression. This trend of growth in basic-research funding, if it were to continue from the level of 1966 for 10 years, would result in a Federally supported basic-research program as large as today's total national RDT&E program. Similar growth in the Federally supported RDT&E program over 10 years would result in a Federal RDT&E budget as large as the total Federal budget today. If the economy continues to grow at its present rate, such levels of support for basic research and RDT&E would not be beyond the realm of possibility. However, when we look at the economic environment and the other needs and wants of society, it seems highly unlikely that such growth rates will again be achieved during the next 10 years.

I realize that this is a dangerous prediction. However, all predictions about the future of science and society are dangerous. It is conceivable that there could be a radical weapon development affecting our national strategic posture which would require that another program like the ballistic-missile program be conducted on an accelerated basis. However, such a program, to radically affect RDT&E growth rates, would have to be much bigger than the ballistic-missile program was, because our present RDT&E program already accommodates R&D efforts as large as the original ballistic-missile program. Such are the mathematics of growth. What was the colossal yesterday is today the commonplace.

The mission of the Aerospace Research Laboratories is primarily concerned with research. Research consumes only a small part of research and development, and test and evaluation dollars. But, as we all recognize, it plays a very important part in laying the foundation stones for future progress. Before ARL was founded, we and the scientific and technical community had arrived at a very comfortable philosophy for the research program—a philosophy which I believe is still generally held in the scientific community, but which is being questioned more and more outside the community. Stated in the simplest possible terms, this philosophy was premised on the belief that all basic research is intrinsically a good thing, that it should be limited only by the availability of capable people, and that the nation should support all of its people capable of basic research in such projects as the expanding vistas of science and technology opened up to us. However, when this philosophy was formulated, I don't think we appreciated the degree to which the pursuit of the frontiers of knowledge could lead us in the direction of very large budgets for basic research. These large budgets come about not only because more and more people are attracted to basic research as the budgets expand, but also because, as we seek to explore ever more difficult and obscure areas, the costs of equipment and technical support for research also

expand. And, as the financial requirements for research grow and the needs of various fields come to compete with one another, we inevitably arrive at the question of how to establish priorities for the allocation of funds to these various fields.

The question of assigning priorities in basic research in our original philosophy was presumed not to exist; but I submit that this was too naive a view of the world. The growth process in research is not self-regulating. The more we support research in a given area, the more graduate students there will be trained and motivated in that particular area. This will generate more promising research proposals in this same area which, if considered sound, would inevitably be funded in accordance with our original philosophy and would thereby provide opportunities for the training of still more graduate students in that very same area. This process, of course, could go on ad infinitum. In the language of control engineering, the feedback loop is unstable. There are additional destabilizing feedback loops in the system. For example, the greater the funding of a given area, the greater the representation of influential scientists from that particular area on Government advisory groups recommending the allocation of research funds, and the more public attention and support the activities and accomplishments in that area are likely to draw. There is no doubt but that corrective mechanisms can be and have been devised to stabilize the system; but the tendency to instability is always there to be reckoned with when the system parameters are perturbed.

In this country a substantial fraction of the basic research has been funded by mission-oriented agencies such as the Department of Defense, NASA, AEC, the Department of Health, Education and Welfare, etc. This has been the subject of considerable public debate and it has, at times, been argued that all basic research, and indeed a good bit of research beyond the basic, should be the responsibility of a Federal Department of Science. This proposal has not received a great deal of support from the scientific community; but it has a certain appeal in the light of the philosophy of conducting research for its own sake, and a desire on the part of some to isolate scientific research in the academic environment from the problems of the Nation.

It is interesting, at this point, to note what a leading British scientist, Sir Gordon Sutherland (who for a time had lived in the United States) has said with regard to the mission orientation of research. In comparing the American method of financing basic research through a large number of Government agencies with the British method, in which there is one Government department which controls almost all of the Government expenditures on basic research, he stated, "A Government department which has the responsibility of providing the science and technology required in the solution of its problems is likely to make more effective use of science than a department of which the scientific needs are met by some central government laboratories which are not under its own control."

Sutherland also had something to say about the relationship between pure and applied science. "Another source of strength to the U.S. university system is that its staff have never been ashamed of the fact that some of the research work can be directed to the solution of current problems of great practical import. This has made the industrialists and the state legislatures more appreciative of *all* of the academic work in the universities and correspondingly more generous in their benefactions and grants." Speaking of the British system, he said, "This can lead to difficulties. How does one justify the size of a national budget for basic research or its apportionment among the various sciences? So long as basic research was relatively inexpensive, it was possible to finance every promising project. Nowadays, however, basic research in physics in Britain costs more than all Government research in agriculture or medicine. Perhaps the time has come for us to identify more of our basic research with specific national objectives in order to achieve a more rational distribution of funds among the different sciences."

The drive toward full utilization of our scientific potential on the frontiers of knowledge has had the inevitable effect of raising the cost of research. In the recent past, distinguished scientific committees and panels at the national level

have pointed out the need to increase funding for research in fundamental particle physics, radio astronomy, optical astronomy, chemistry, and oceanography, among other fields. In most of these cases a large investment in research facilities and research instrumentation equipment is implied. The cost of equipment seems to be on an ever-increasing upward spiral, advancing much more rapidly than the cost of scientists actually engaged in research. This is contagious, moving from fields at the frontiers of science to those somewhat in the rear. Even research in the humanities is now coming to require a high-speed digital computer in many cases. This increasing cost of equipment for research may lie in considerable part at the root of Derek De Sola Price's observation in his book, *Big Science - Little Science,* that the cost of research rises as the square of the number of people involved.

The effect of the support of a substantial fraction of fundamental research in this country by mission-oriented agencies has been for them to provide a means of orienting the research efforts in this country and of emphasizing some fields more than others. Now by this I do not mean that a physicist doing research in plasma physics under the sponsorship of the Department of Defense will in any way be constrained to orient his research toward some specific conception of a weapon system or a communications system which might possibly result from his work on plasmas. On the other hand, all other things being equal, the Air Force should more likely be supporting work on plasmas having characteristics like those in the ionosphere or around re-entry vehicles as opposed to those to be found on distant stars. At the same time, we are aware that it may, in some future decades, be a plasma like that on some distant star which is relevant to some defense problem. Each mission-oriented agency seeks to stimulate research in those areas deemed most likely to relate to its own interest. Looking over the entire field of science is the National Science Foundation, assuring that no promising area of research is overlooked merely because the vision of the mission-oriented agencies is too short. However, it is undoubtedly the pressure of support by the mission-oriented agencies which sets the absolute scale of the national effort.

I would like to make it clear that I do not think that the growth of basic research in this country is yet near the point where the economic feasibility of further growth is in question. Yet it is at the point where the funds required are large enough to have to compete with the funds needed for other national objectives. This is the major change in the research environment today. Before World War II, the progress of science was largely a matter of private initiative. Individual scientists or small groups of scientists could follow those paths which attracted them or which seemed to have the most promise. In the period after World War II, national expenditures for research and development increased steadily for 20 years, until the present significant levels were achieved. Today the decisions as to which paths will be followed most aggressively and with the largest funding have become a matter of public policy. Thus, it is inevitably true that a full understanding of and support for research on the part of the public as well as the research scientists' immediate customers (I use the term advisedly), the applied scientist and the engineer, is now needed if continuing growth in research support is to be realized.

The percentage of the total labor force required to produce the necessities of life both in agriculture and manufacturing has declined steadily from 75 percent 50 years ago to only 45 percent today; and the end is not yet in sight. Technology, since the beginning of mankind, has served to free man from manual labor and burden him with more intellectual pursuits as well as reward him with leisure. However, it is obvious that in this country, at present, we have some very massive problems in the reallocation of the labor force to meet the changing needs of commerce and industry brought about by technology. We must learn to do this better and more systematically if we are to live on a continuing basis with the rapid changes in the economy and the social order which technology can bring about.

In an earlier age the distinguished scientist, Coulomb, expressed a view of the contributions which might be made to science by those less gifted than the leaders

in science. He said, "Each citizen ought to contribute to them according to his talents. While great men will be carried to the top of the edifice where they can mark out and construct the upper storeys, ordinary artisans who are scattered through the lower storeys or are hidden in the obscurity of the foundations should seek only to perfect that which cleverer hands have created." The thoughts which Coulomb expressed are, I believe, relevant today. But if an ever-increasing fraction of the resources of society are to be devoted to science, an ever-greater number of people will have to derive aesthetic, intellectual and material values from this activity.

And now to return more specifically to the functions of the Aerospace Research Laboratories–research on behalf of national defense. We have a somewhat different situation than the general one described above, but one which requires somewhat the same enlargement of public understanding and support. There is no doubt but that the majority of our citizens and members of Congress fully support the development of those weapon systems necessary to assure our national security. What is not so clear to them, however, is the validity of research in all the areas which seem to them to be remote from weapon-system needs. There is a growing doubt in the minds of many that we are really being selective and effective in our basic research. Indeed, our research scientists have striven so hard to make themselves indistinguishable from academic research scientists, in the public eye, that it has become difficult to argue that there is anything special about basic research related to national defense. This situation has both its good and its bad features. Let me make clear that I believe it is possible to be a good basic-research scientist and, at the same time, to have practical interests. I realize that views on this vary widely; but I can do no better than to cite the example of Pasteur, who made his major contributions working on the problems of the silk-worm disease, fermentation of beer, and a means of cure or prevention for rabies–all good, solid, applied problems. Yet out of these came some startlingly good basic research: the germ theory of disease, which had much broader application. The best part of this story is that Pasteur *did* find the solution to the applied problems he was attempting to solve. He *did* find methods to improve the fermentation of beer; he *did* find a preventive for rabies; and he *did* find a way to alleviate the silk-worm disease. He accomplished all of these things because of, and not in spite of, the fact that he took a fundamental approach to his problems. Pasteur stated his view simply: "There are no such things as pure and applied science–there are only science and the application of science."

It is interesting to note what Helmholtz said when he visited Sir William Thomson, whom he found absorbed in regulators, and measuring apparatus for electric lighting and for electrical railways: "On the whole, however, I have an impression that Sir William might do better than apply his eminent sagacity to industrial undertakings; his instruments appear to me too subtle to be put into the hands of uninstructed workmen and officials, and those invented by Siemens and Hefner v. Alteneck seem much better adapted for the purpose. He is simultaneously revolving deep theoretical projects in his mind, but has no leisure to work them out quietly; as far as that goes, I am not much better off." And he adds immediately after, "I did Thomson an injustice in supposing him to be wholly immersed in technical work; he was full of speculations as to the original properties of bodies, some of which were very difficult to follow; and, as you know, he will not stop for meals or any other consideration."

Another contrary view of the relationship between pure and applied science was that of David Hilbert, the famous German mathematician, who said: "We are often told that pure and applied science are hostile to each other. Pure and applied mathematics are not hostile to each other. Pure and applied mathematics will never be hostile to each other because, in fact, there is absolutely nothing in common between them." That Hilbert thought this way is particularly remarkable because few mathematicians of his era produced so much applicable mathematics. It is as if, in spite of himself, he produced the very form of mathematics which was needed for upcoming applications to scientific and technical problems. An opposing view by a modern mathematician, von Neumann, was that much of mathematics was advancing into relatively sterile fields because it had become fashionable to insist on working in areas that had no foreseeable application. His feeling was that such mathematics is cut off from the stimulus, the insights, and the discipline which real-world problems provide.

From all of this we can conclude that basic research is neutral with respect to applications. The motivation of the scientist who performed certain research is not left imprinted on the results of that research. These are old and widely accepted truths; but some have jumped from this to the conclusion that basic research, to be so defined, must always be unmotivated by any interest in practical application. This, of course, as our examples illustrate, is at best a convenient fiction. It is true, however, that if immediate application is the objective of a research program, it can quickly be diverted from some of the most promising areas of basic research and, in the extreme, can become nothing more than another engineering project.

The Aerospace Research Laboratories are, and of course should be, mission-oriented. This orientation is, and should be, to the United States Air Force. Whether ARL's projects are classified as basic or applied research, or lie somewhere in between, is of less consequence than that its projects be relevant to future Air Force needs, that they be of high scientific quality and promise, and that they be conducted by competent and creative scientists. In all these respects I think that ARL has made significant progress during its first 20 years. But excellence is a goal which, paradoxically, once achieved, is on the way to being lost. It must be constantly striven for. Thus ARL, in the next 10 years, must look forward to even greater effort to achieve even greater excellence, and more critical standards by which to judge that excellence.

As I have noted above, it is hardly to be expected that the next 10 years will see the same over-all rates of growth in research activities as the last 10. In fact, such growth is not likely to be achieved again until there has been a better adjustment of society to the strains imposed by the rapid march of science and technology. The research needs of national defense have their own imperatives. There are vast areas of science and technology which must be explored to identify opportunities for ourselves and for our allies, and to guard against technological surprise from potential enemies. Much as we may strive to attain a peaceful world by political means, it is difficult to see a time when we will not need to remain alert on the scientific and technological front. The size and shape of our military forces in being at any given time will, of course, be conditioned by the contemporary political and military state of the family of nations; but the sensitivity of this state to scientific and technological advance will require watching for as far into the future as one can contemplate. In this task we shall look forward to the continuing contributions of the Aerospace Research Laboratories in support of the Air Force mission and national security as a whole.

MANAGEMENT OF RESEARCH AT ARL

COL PAUL G. ATKINSON, JR.
Commander, ARL

Since 1 April 1961, the Air Force has assigned responsibility for its fundamental research to the Office of Aerospace Research (OAR), a separate operating agency, with headquarters currently at Arlington, Virginia. OAR is under the Command of Brig General Leo A. Kiley who reports directly to the Chief of Staff, USAF (see Figure 1).

The Office of Aerospace Research has five major research elements. These include ARL; the Air Force Cambridge Research Laboratories (AFCRL) at L. G. Hanscom Field, Bedford, Massachusetts, which does research in the physical, engineering and environmental sciences; the Air Force Office of Scientific Research (AFOSR) at Arlington, Virginia which, through contracts and grants, operates a program of research relevant to the Air Force in scientific areas across the board; the Frank J. Seiler Research Laboratory (FJSRL) at the USAF Academy, Colorado; and the Office of Research Analyses (ORA), (Det. 8, Hq OAR) at Holloman Air Force Base, New Mexico. ARL, AFCRL and AFOSR work through the European Office of Aerospace Research (EOAR), a research-supporting unit, for procurement in Free Europe, the Near East, Middle East, and Africa, of research efforts in support of their own programs. The Latin American Office of Aerospace Research (LAOAR) (Det. 7, Hq OAR) at Rio de Janeiro, Brazil administers research efforts in South America. In addition, three field offices–the Patrick Field Office (PFOAR) (Det. 4, Hq OAR) at Patrick AFB, Florida, the Los Angeles Field Office (LOOAR) (Det. 6, Hq OAR) at Los Angeles, California, and the Vandenberg Field Office (VFOAR) (Det. 9, Hq OAR) at Vandenberg AFB, California–support the aerospace research effort by maintaining liaison among the scientists, the launch teams, and the contractors. (See Figure 2)

The mission of ARL is to conduct in-house research in areas of the physical and engineering sciences which offer the greatest potential for the

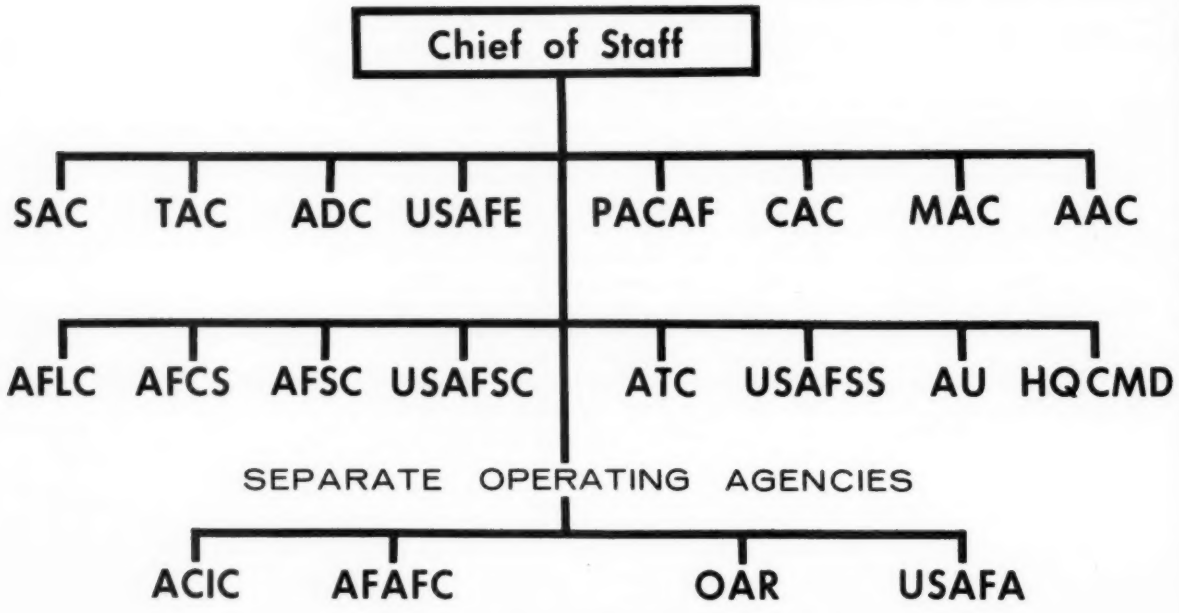


Figure 1. Major commands and separate operating agencies.

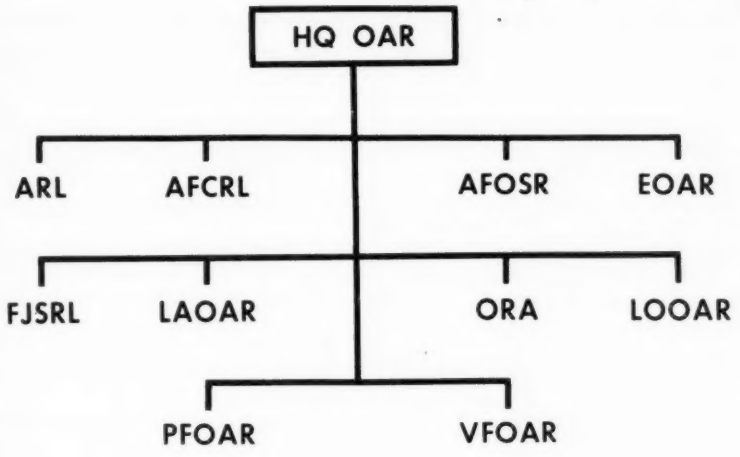


Figure 2. Office of Aerospace Research

operational capability of the Air Force. Some research is contracted in support and extension of the in-house efforts. In the last few years at ARL, there has been an increasing emphasis on getting the results of fundamental research to the user, and considerable effort goes into this. The responsibility for coupling rests with each scientist and with management at all levels. This effort, although it has always been present, has expanded in the last 4 or 5 years to about 15% of the total effort. In recognition of this, it has been incorporated into the ARL mission—to participate in efforts to reduce the lead time between the discovery of new knowledge and its application for operational superiority of the Air Force.

ARL is organized into five laboratories in the physical sciences and five in the engineering sciences. Those in the physical sciences are: the Chemistry Research Laboratory, the Plasma Physics Research Laboratory, the Applied Mathematics Research Laboratory, the General Physics Research Laboratory, and the Solid State Physics Research Laboratory. Those in the engineering sciences include: the Energetics Research Laboratory, the Fluid Dynamics Facilities Research Laboratory, the Thermomechanics Research Laboratory, the Hypersonic Research Laboratory, and the Metallurgy and Ceramics Research Laboratory.

Over the years, ARL has performed several roles in addition to its in-house research and coupling. Being in close proximity to the DOL (AFSC) Laboratories and Aeronautical Systems Division (AFSC) at Wright-Patterson Air Force Base, it is natural that considerable consulting occurs in areas of mutual interest. And, in fact, it takes place with scientific and technical agencies all over the United States.

Although the subjects selected for in-house research are necessarily specialized in order to make meaningful contributions, ARL scientists, as professionals, must follow the broad progress of science worldwide. This "window-to-science" role in many areas provides for the interpretation of discoveries wherever they occur in terms of Air Force interests.

In addition, there is a training role. Annually, about 20 or 30 Master's-Degree student officers from the Air Force Institute of Technology (AFIT) accomplish their theses at ARL on subjects involved with the research under way. A Ph.D. program has also been initiated. Two officers have been assigned to do their doctoral dissertation at ARL and to remain with the organization for two more years following completion of their Ph.D. work. A number of ARL scientific personnel, who are accredited as Adjunct Professors, teach at AFIT; and a number of the AFIT faculty, designated as Research Associates, do research at ARL.

The organization of the Aerospace Research Laboratories is straightforward, as shown in Figure 3. The primary responsibility of the staff offices on the top line is to service and support the individual laboratories and relieve them of their administrative work load as much as possible. This permits the scientists to devote more of their time and attention to the actual conduct of research.

ARL experienced a steady growth in manpower during the early 60's, and leveled off at about 325 in 1965.

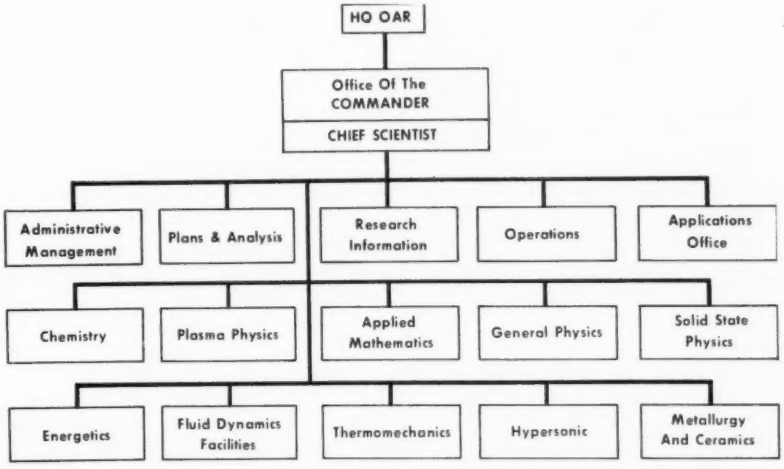


Figure 3. Aerospace Research Laboratories

The *OAR Five Year Plan* projects this plateau through FY 1969 with a growth of 50 in FY 70 and 23 additional in FY 71. As can be seen in Figure 4, the ratio of civilian to military remains at about 3 to 1, with a fairly uniform distribution at all levels of management. For example, 3 of the 10 laboratory directors are military at this time.

Figure 5 below indicates that the academic level at ARL has grown to about 75 Ph.D.'s, and about the same number with a Master's Degree. Provision is made within the training plan for both military people and civilians to advance their academic qualifications while serving at ARL.

Available floor space has shown a 50-percent growth since the main laboratory was completed 10 years ago. The General Physics Research Laboratory, with its 2-MeV and 8-MeV accelerators, is now housed in Building 57. Minor construction has augmented the floor space of the main building, and 26 portable office units have popped up like mushrooms. While they give the appearance of a shanty town, the portable office units are very practical for office space and light experimental work. A few temporary buildings have also been added, as well as one remote facility for observing satellites (See Figure 6).

The plant worth, including buildings, service, and experimental facilities and equipment, is just short of 30 million dollars (as seen in Figure 7). ARL, for its size, is one of the best-equipped laboratory complexes in the world.

A recent aerial view of ARL shows the building layout with portable office units and certain of the experimental facilities (Figure 8).

The budget of ARL enjoyed a steady growth in the early 60's, reaching a plateau of 13.6 million for the last three years. The important thing for research is that there have been no sharp ups and downs, which can be so damaging to research. (Budget details

	FY 64	FY 65	FY 66	FY 67	FY 68	FY 69	FY 70	FY 71
Civilians	226	244	246	243	236	236	286	309
Military	72	83	82	83	86	86	86	86
Total	298	327	328	326	322	322	372	395

Figure 4. ARL Manpower

	'64	'65	'66	'67	'68
PhD ⇩	62	74	73	75	72
MS ⇩	55	69	76	80	73
BS ⇩	42	37	34	34	38
Total	159	180	183	189	183

Figure 5. ARL Academic Level

Building 450	121,125 Sq. Ft.
Building 451	5,820
Building 57	30,600
Vacuum Sphere Enclosure	1,960
Portable Office Units (Temp)	29,800
Thrust Augmentation Bldgs (Temp)	2,620
Sulphur Groves Facility (Temp)	400
GROSS AREA TOTAL	192,325 Sq. Ft.
Minus Total Temporary Space	32,820
Minus Halls, Stairways, Etc.	30,660
TOTAL PERMANENT USABLE SPACE	128,845 Sq. Ft.

Figure 6. ARL Floor-Space Statistics

	1966	1967	1968
Building Facilities	$ 5,361,049	$ 5,926,049	$ 6,309,736
Service Facilities	6,125,000	7,750,000	7,965,000
Experimental Facilities	1,795,000	3,995,000	5,030,000
Sub-Total	$13,281,049	$17,671,049	$19,304,736
Equipment	9,250,000	9,345,000	9,915,000
Total	$22,531,049	$27,016,049	$29,219,736

Figure 7. ARL Plant Worth

Figure 8. The Aerospace Research Laboratories

are depicted broadly in Figure 9.) The line of "total support," which is indicative of the in-house capability, has grown steadily over the years. The contract research program, level for some years, is now turning down as in-house capabilities and personnel increase.

ARL is a tenant at the Wright-Patterson Air Force Base. The equivalent of 30 man-years of support are furnished by AFSC's Aeronautical Systems Division in the areas of accounting, administrative services, civilian personnel, civil engineering, shop service, photo, printing, computer service, and procurement of R&D. The WPAFB-based 2750th Air Base Wing of AFLC provides an additional 46 man-years of support in pay, supply, transportation, custodial services, procurement of equipment, photo services, civil engineering, and military services.

The tenancy agreements formalizing these arrangements are updated periodically. The fact that there have been no problems of any consequence has been of distinct benefit to ARL and its research mission.

In a brief overview of ARL from a management standpoint, there are perhaps three areas to consider. First, there is the administrative or housekeeping function. ARL is much like any other organization in terms of personnel, manpower, budget, supply, etc. However, it is important to note that the Office of Aerospace Research has provided simplified procedures and permitted the field units unusual flexibility at the operating levels. This has been of great benefit.

A second function of ARL management is to provide the proper environment for research. Every effort is made to obtain highly competent scientists, and to establish a creative, almost university-type atmosphere, which will be conducive to research. Within the scientific areas, which are relevant to Air Force interests in either the long or short term, the researchers are given the scientific freedom to pursue whatever problems they deem appropriate. They are given the best support possible for required equipment and supplies. Every effort is made to reduce their paper work, and to grant them appropriate reward and recognition for their work. However, the responsibility for coupling the results of research with the user has been included in the job description of each scientist, and a program review in depth is held at least once a year. Beyond this, there is very little else that management can do to increase productivity in research. New knowledge and ideas just have to hatch. And, given the proper environment, they usually do. (See Figure 10)

A third function of ARL management involves coupling. This is an area in which management can bring its weight to bear, and every effort is made to do so when the opportunity arises. Coupling is time-oriented, in

	FY 64	FY 65	FY 66	FY 67	FY 68
PAYROLL	2,481	2,877	3,064	3,191	3,234
TRAVEL	119	133	128	124	135
S.M.& E.	2,354	1,892	1,496	1,944	2,124
OTHER SUPPORT	396	518	551	907	1,041
TOTAL SUPPORT	5,350	5,420	5,239	6,166	6,534
CONTR. RESEARCH	5,606	6,280	7,161*	6,791**	5,181***
DRS SUB TOTAL	10,956	11,700	12,400	12,957	11,715
DIRECTOR'S FUND	713		600	500	312
TOTAL TO ARL	11,669	11,700	13,000	13,457	12,027
MILITARY PAY	448	620	650	954	989
MCP	- - -	- - -	- - - -	- - -	- - -
GRAND TOTAL	12,117	12,320	13,650	14,441	13,016

* INCLUDES 69K UNOBLIGATED FY 66 FUNDS FROM OAR

** INCLUDES 450K FOR PROJECT THEMIS
INCLUDES 350K UNOBLIGATED FY 67 FUNDS FROM CRL

*** INCLUDES 216K FOR PROJECT THEMIS

Figure 9. Budget (Thousands of Dollars)

two respects. First, one cannot predict when a discovery is going to be made. Second, once it is made, it is generally desirable to get the results into use as soon as possible.

Each case is unique in one way or another; the problem is to find the best way to transplant this knowledge to using agencies. It is the responsibility of the individual scientist to determine who his best customer would be, and how to go about coupling. There is a gap between research and development—and the problem of bridging this gap is given a great deal of attention.

The Applications Office of ARL was created in 1966 to promote coupling and to assist the scientists in any way. The applications officers assess both the potential of an idea and its market. They serve as outside salesmen and act as the focal point for any problems of an administrative nature that the scientists may encounter.

The first step following a discovery is to communicate its findings. For this purpose, ARL employs a variety of means, among which personal contact is perhaps the single most effective method. (See Figure 11)

If a new technique, concept, or discovery is judged to be useful, one must then find a user. This is the classical way; and it makes life very simple when an outside agency will carry on the work to application.

Frequently, it becomes apparent that there is more homework to be done. The researcher must often build up his case in order to validate the potential of a discovery or concept. Sometimes an operational-analysis or cost-effectiveness study may be appropriate, in which case the Office of Research Analyses would be asked to undertake this work.

In most instances, a new approach must compete for program support against a host of other existing efforts. Many results of research, while offering promise, are only preliminary and inconclusive. Customers, on the other hand, are usually very practical. On occasion, when asked or directed, ARL has "bent tin." When a specific expertise or know-how has been generated, and a research program has gained momentum, a research organization can sometimes carry through a development more quickly and with less cost than farming it out to someone else. Such instances are the exception; but sometimes it makes sense to couple directly with the user of an end item.

The challenge to management is to reduce the lead time in getting new knowledge to the inventory, while at the same time maintaining the proper research environment which will foster a continuing evolution of new knowledge. Also, the seeds of knowledge generated in in-house laboratories usually have to be transplanted to industry in order to grow and flourish before they can find their way into the developmental inventory. For this purpose there is the applications contract. To insure the timely application of new knowledge, it is sometimes necessary to select and fund an industrial contractor to help bridge the gap.

Another positive ARL coupling mechanism is provided by the setting up of a cooperative program with an Air Force development laboratory. A jointly funded contract program or in-house effort is very effective as a means of coupling since both ARL and the other organization then have an interest, objective, and responsibility in common.

- OBTAIN & RETAIN HIGHLY COMPETENT SCIENTISTS
- PROVIDE CREATIVE ATMOSPHERE
- SCIENTIFIC FREEDOM
- TIMELY SUPPORT
- ADMINISTRATIVE RELIEF
- COMMENSURATE REMUNERATION
- COUPLING

Figure 10. ARL Implementation of OAR Management Policy

- OAR RESEARCH APPLICATIONS CONFERENCE
- OAR PROGRAM REVIEW
- COUPLING CONFERENCES ESD, ASD, SAMSO/DOL
- DOL MOST WANTED RESEARCH
- TDY AT ASJ
- SPECIAL PROJECTS AND BRIEFINGS
- VISITS TO OPERATIONAL COMMANDS
- INDUSTRY BRIEFINGS
- SPONSOR SYMPOSIA
- PERSONAL CONTACTS
- MEMBERSHIP ON PANELS AND COMMITTEES
- PUBLICATIONS AND PRESENTATIONS

Figure 11. Communications

RESEARCH AREAS IN THE 10 ARL LABORATORIES

Chemistry Research Laboratory

DR. JAMES A. BIERLEIN, Director

The Chemistry Research Laboratory is one of the oldest at ARL. It is charged with the responsibility of conducting research in chemistry and chemical engineering in support of the Air Force mission. In view of the scope of this field, it is incumbent upon us to be selective in our undertakings. Our program at the present time proceeds along the following six avenues of investigation:

Molecular Transport Process
Surface Phenomena
Ion-Molecule Reactions
Flames and Detonations
Metal Chelate Compounds
Organosilicon and Perchlorocarbon Chemistry

The first three of these may be categorized as lying in the fields of physical chemistry and chemical physics.

Efforts in molecular transport processes are focussed on diffusional and thermodiffusional processes in liquids. On the one hand, some rather fundamental problems in the structure of liquids are being examined; on the other, consideration is being given to some fairly practical problems in the purification and separation of materials.

Our work on surface phenomena comprises the examination of ultraclean surfaces by electron-diffraction techniques (see photo). Interest lies in the structure and energetics of these surfaces with a view to the elucidation of such practical phenomena as gas adsorption, adhesion, corrosion, semiconductivity, and superconductivity.

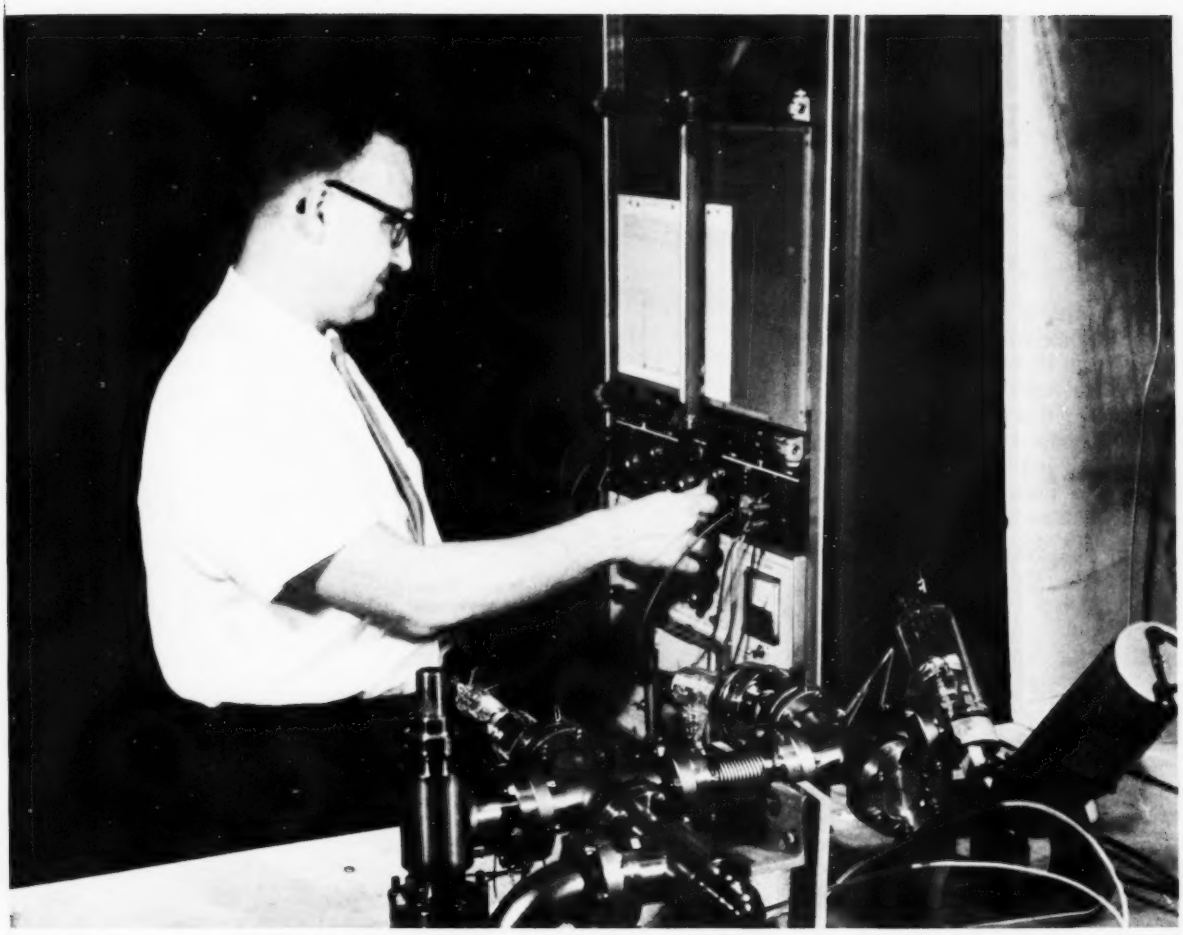
Ion-molecule reactions characterize the chemistry of the upper atmosphere as well as the reactions of substances subjected to ionizing radiation. We believe that our excellent equipment, developed under the guidance of our staff, endows us with unique capabilities for research in this area.

Any Air Force chemistry research effort would be expected to have a program in combustion. Its relevance hardly needs discussion. Our chemical engineers are examining both flames and detonations. Recently, some of their work has been rather closely connected with problems arising in southeast Asia.

Inorganic chemistry in our laboratory has become pretty much synonymous with the study of metal chelate compounds, which have many remarkable properties. The most dramatic of these is their volatility, a fact discovered here. This permits treating metals as gases, enabling them to be subjected to such processes as gas chromatography and distillation. New vistas have been opened up thereby in chemical analysis and the ultrapurification of materials. We are proud of the citation of this work in the 1967 *Yearbook* of the *Encyclopedia Britannica* as one of four outstanding accomplishments in world chemistry for that year.

Finally, our organic chemists are investigating unique types of organic compounds. They are examining two classes of compounds which have properties quite startling and bizarre compared to those with which we are accustomed. This work is quite naturally motivated by the Air Force's demand for materials to meet increasingly stringent requirements transcending those that can be satisfied by currently available substances.

It is always interesting to look at statistics which measure the productivity of a work effort. The accompanying illustration (Figure 1) presents indices appropriate to a research organization whose output may be properly gauged in terms of the scientific information it produces. For the 10-year period covered, the figures show a pleasing upward trend. We are happy to note that our participation in coupling with the development community has grown in a parallel fashion as our reputation has increased.



ARL scientist investigating low-energy electron diffraction on a clean surface of vanadium.

✶✶ *SCIENTIFIC OUTPUT* ✶✶

	'58	'59	'60	'61	'62	'63	'64	'65	'66	'67
JOURNAL PAPERS	7	5	13	16	19	20	15	30	49	49
BOOKS	0	0	0	0	0	1	1	2	1	0
PRESENTATIONS AT SCIENTIFIC MEETINGS	4	6	7	12	21	19	24	37	49	51

Figure 1. Scientific-information output at the Chemistry Research Laboratory, ARL.

Energetics Research Laboratory

LT COL MELVIN R. KELLER, Director

"Energetics" is defined as that branch of mechanics which deals with energy and its transformation. In the Energetics Research Laboratory, that broad definition has been narrowed to include only fluid-dynamic energy conversion and transformation processes. The related research areas are discussed below.

In fluid-dynamic electrical-energy conversion, the principal research effort has been in electrofluid-dynamic (EFD) processes that convert the energy of a flowing gas directly into electrical energy without the need for moving parts or external magnetic fields.

The fluid-dynamic energy-exchange area is concerned basically with research in energy interactions between gas-gas, gas-liquid, and liquid-liquid flow systems.

In multicomponent flow research, investigations are concentrated on supersonic swirl and curved flow, ultramicroscopic particle separation, condensation processes, and particle suspension and mixing.

Exploratory investigations have to do with the theoretical development of new areas suggested by other research. Methods are also developed to determine the needed data from unique experiments in the preceding three areas.

In addition to the purely fundamental research which constitutes the Laboratory's main effort, those research results which show promise of advancing further the aerospace technology of the United States Air Force are exploited by the introduction and initial investigation of operational concepts and specific applications. Examples of these concepts and applications are the colloidal core reactor, particle separation, thrust augmentation, and EFD power generation.

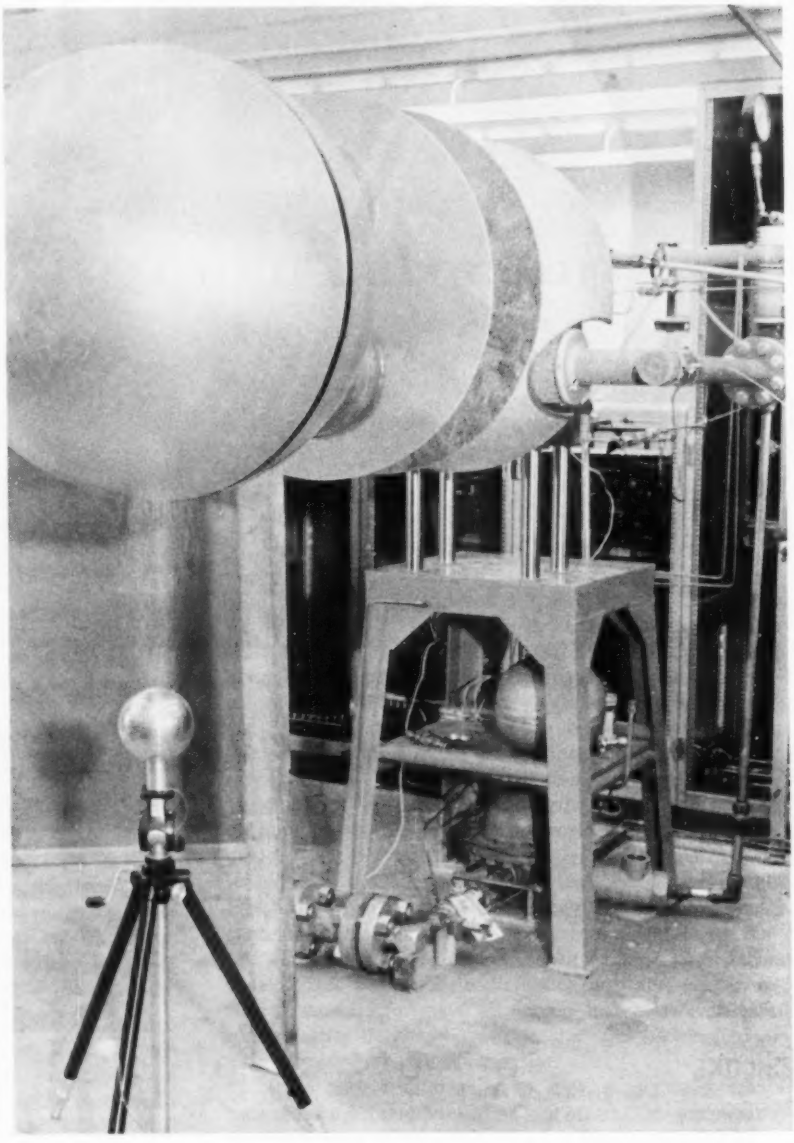


Figure 1. Electrofluid-dynamic (EFD) equipment in operation.

Fluid Dynamics Facilities Research Laboratory

ELMER G. JOHNSON, Director

Beginning with the Wright brothers' first crude wind tunnel, there has been a consistent, growing need for more and more sophisticated means for duplicating flight environments in laboratory facilities. The Fluid Dynamics Facilities Research Laboratory program is an interdisciplinary one concerned with major areas of importance to the Air Force in the development of its future weapons.

Our work in the hypervelocity flight-duplication area varies from methods and devices such as the implosion technique, the traveling-wave pump, the isentropic compression tube, the velocity augmenter, and coupling laser energy to a gas for accelerating models, through supersonic combustion simulation as it applies to scramjet engines. The primary objective is to attain for the USAF, through research, laboratory capabilities for duplicating flight phenomena at velocities approaching 100,000 ft per second.

High-performance turbomachinery is a subject of continuing interest to the Air Force. One of our program objectives is to establish a fundamental understanding of the flows through highly curved passages at supersonic speeds in order to realize a theoretical performance available from such devices as supersonic compressors.

In the gas-dynamics and diagnostics area, we have a continuing program of study on real gas effects and on the phenomenon of air liquefaction as occurs under accelerated flow conditions in hypersonic nozzles. Also, a program of study of new techniques for sensing, collecting, and processing experimental data is under way. The objective of this work, broadly speaking, is to find new and improved methods for the measurement and interpretation of experimental data.

Finally, we are concerned with research on a variety of aerospace simulation facilities, ranging from our Mach 14-20 hypersonic wind tunnels and their high-performance components, through high Reynolds-number-type facilities, such as we now have under construction at the Laboratory. Also, there are efforts in heat transfer and other areas, pertaining to the facilities field, which we are carrying on under this program title.

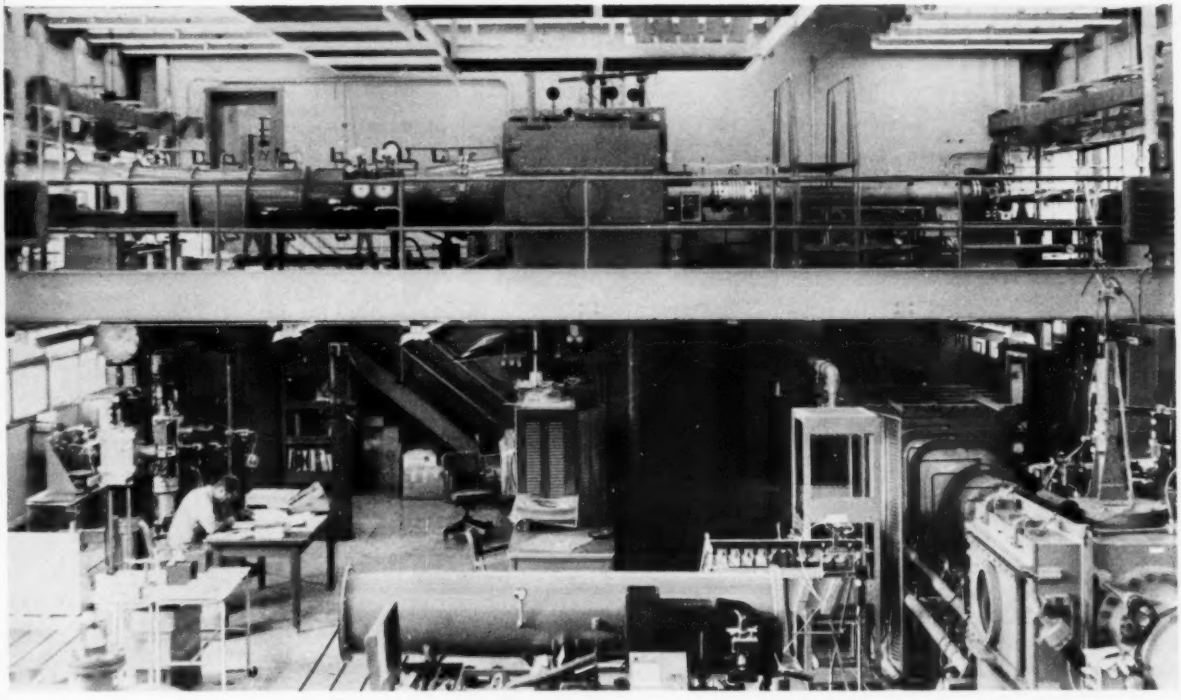


Figure 1. Over-all view of hypersonic wind tunnels at ARL.

Plasma Physics Research Laboratory

LT COL RICHARD C. WINGERSON, Director

The Plasma Physics Research Laboratory is conducting research in three major areas selected to provide a broad coverage of physical phenomena observed when matter is in its highest temperature state.

In atomic and molecular physics, we are seeking to understand in detail the behavior of particles at high temperatures and at plasma densities where the effects of collisions between particles are important. Radiation transport is emphasized.

In gaseous electronics we study the energy-exchange processes occurring in plasma ionized to only a few percent at most. We have done extensive work on excitation waves and have developed the capability to fabricate our own gas lasers as required.

In controlled nuclear fusion we are looking at the questions of stability and plasma heating with the goal of developing design factors and scaling laws for a new approach to these rather intractable problems.

In all areas we place great emphasis on the use of precise diagnostic procedures with heavily automated data-acquisition and processing techniques. Use of this modern instrumentation is rapidly giving us a leading national position in our areas of most intense specialization.

The areas we have selected for emphasis are particularly relevant to existing and potential Air Force problems. The understanding of radiation transport which comes from atomic-physics studies is important in nuclear-weapons effects, vehicle heating on re-entry from space, and wall heating in advanced energy-conversion systems. Other aspects of atomic and molecular physics increase our understanding of solar processes and hence the entire space environment, and also contribute to our understanding of gas lasers. Studies in gaseous electronics underlie the development of broad classes of gas lasers as well as direct thermionic power-conversion systems. Finally, nuclear fusion offers the greatest potential for space propulsion systems if it can be controlled.

Work in our Laboratory is concentrated on fundamental physical processes; but the selection of individual tasks is motivated by our awareness of gaps in knowledge which seem to be impeding Air Force technological progress.

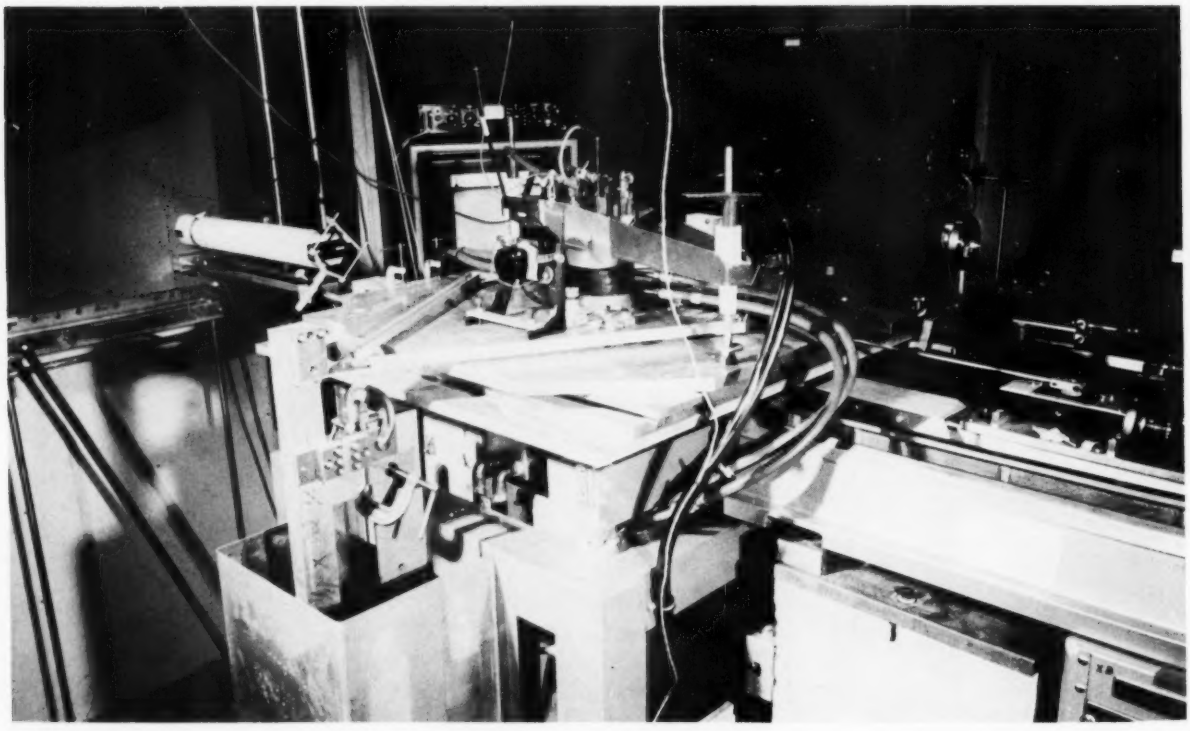


Figure 1. Hydrogen vortex arc facility used in high-density studies.

Applied Mathematics Research Laboratory

DR. LYNN E. WOLAVER, Director

The Applied Mathematics Research Laboratory is concerned with the application of mathematics to Air Force needs and the development of new mathematical techniques required to solve current and future Air Force problems. A variety of areas are covered under the broad topics of mathematical physics, probability and statistics, computational analysis, and the application of analysis.

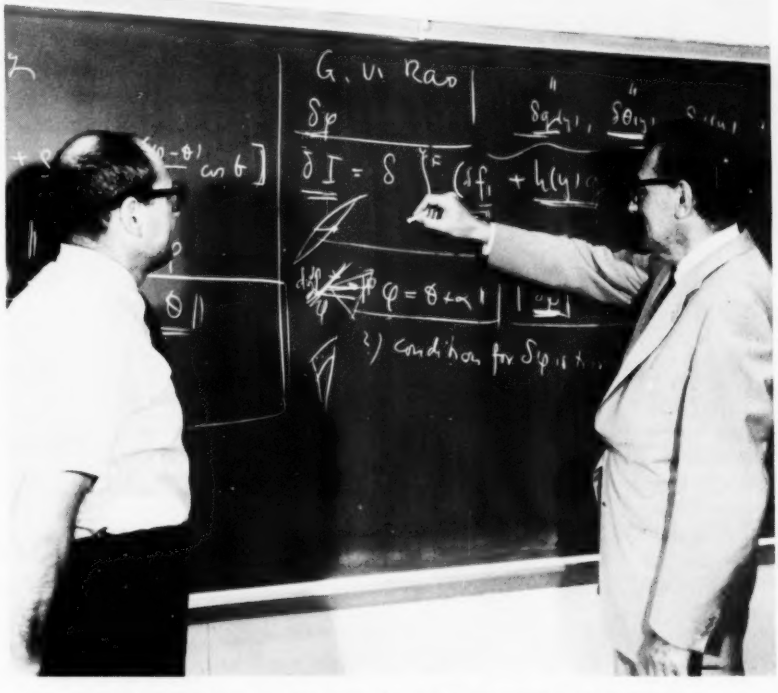
The objective of research in mathematical physics is to obtain valid mathematical models and to develop methods of obtaining usable solutions which take into account the constraints imposed by the physical problem. Examples of work in this area include the following: determination of the optimum supersonic thrust nozzles; swirl flows with closed stream lines; computation of axial symmetric transonic flow patterns by the unsteady-flow approach; investigation of the onset of turbulence by numerical integration of the Navier-Stokes equation; and statistical theory of inhomogeneous turbulence. Also included are studies of the theory of spherical plasma probes in a monoenergetic plasma, and the theory of plasma oscillations. The latter studies have led to a new method for the detection of clear-air turbulence which shows great promise. Work is also being carried out in celestial mechanics, optimal control, and the development of a mathematical model for the blood-sugar regulation of the human body.

The studies in probability and statistics cover a good deal of work which has immediate application and relevance to Air Force problems. The topics include probability and the analysis of variance, statistical distributions and estimation of parameters, multivariate analysis, and allied topics.

The third area of computational analysis is an essential part of the proper use of scientific computers. Work in this area includes research in approximation theory, the determination of error bounds for the numerical solution of systems of linear differential equations, and the computation and analysis of various special functions.

The fourth area of application of analysis includes such topics as linear algebra and matrix theory, the study of inequalities, linear and nonlinear programming theory with applications to control theory, and the theory of functional analysis. The Laboratory maintains a "listening-post" activity in the more abstract or "pure" area of mathematics in order to be aware of new tools with which to solve current and future Air Force problems. Many physical problems can not be solved because the available mathematical tools are not adequate. Thus it is essential, in order to solve future Air Force problems, to "put some money in the bank" by developing mathematical techniques per se. These represent a fount of inspiration for the application of mathematics. It is, therefore, a necessary and important part of the program to be concerned with subjects that appear rather "pure" but which have potential value for applications.

The scope of problems studied by the Applied Mathematics Research Laboratory thus cover the range from the more abstract to such practical problems as how best an aircraft can patrol the jungles of Vietnam to obtain the maximum amount of reconnaissance data.



Mathematicians at ARL discussing problem in mathematical physics.

Thermomechanics Research Laboratory

LT COL DONALD E. DYE, Acting Director

Personnel of the Thermomechanics Research Laboratory are conducting studies in the following major research areas:

convective heat transfer
plasma acceleration and magnetic-field interactions
high-temperature diagnostics
high-pressure arc discharges
theoretical interactions (CTR)

The first research topic is under the leadership of Dr. Max G. Scherberg. He is concerned with studies on the heat-transfer effects on surfaces with streamwise vortex systems (which may be an important new heat-transfer mechanism), and on the enhanced heat transfer in two-phase flow systems. His efforts are largely analytical in nature; however, experimental investigations are being conducted at the Arnold Engineering Development Center (AFSC) and at the Air Force Institute of Technology.

The second research-topic area is under the leadership of Dr. Herbert Schrade. He is particularly interested in the containment problems of very-high-temperature plasmas as they apply to controlled thermonuclear-reactions research.

Mr. Paul Schreiber is the senior scientist responsible for the third research-topic area. Emphasis in this research area is placed on the development of techniques and devices for high-temperature plasma diagnostics, and on the measurements of high-temperature plasma transport properties. This research area also directly supports the other plasma experimentation being conducted within the Laboratory.

The fourth research-topic area covers the research being conducted on very-high-pressure plasma properties and characteristics. Experiments are planned for steady-state plasma operation up to 1,000 atmospheres pressure.

The fifth research topic is under the direction of Mr. Ken Cramer who is concerned with problems pertaining to microinstabilities in high-temperature plasmas. Emphasis is placed on problems which have particular application to controlled thermonuclear reactions. The Laboratory's efforts in magnetohydrodynamics (MHD) research, which is being gradually phased out of the program, are also being carried out under this research-topic area. At present, experimental studies in MHD are being conducted at the Air Force Institute of Technology.

High-temperature plasma diagnostic measurement experimental device being tested.

General Physics Research Laboratory

KENNETH E. KISSELL, Director

The General Physics Research Laboratory conducts investigations in several distinctly different fields. We have groups of scientists working in the areas of theoretical physics, atomic structure, nuclear structure, and optical physics.

In theoretical physics (about 1/4 of our effort), the emphasis is on nonlinear problems in areas such as quantum field theory, general relativity, crystalline conductors, and stability in high-temperature plasmas.

In atomic structure our work is in the study of energy exchange in atomic systems. Here our emphasis is on line spectroscopy in the visible and vacuum ultraviolet which makes it possible to measure or predict the atomic constants for spectral lines of importance in the remote sensing of temperature and chemical abundance.

Our largest single effort (40%) is in the investigation of the structure of low-to-medium mass nuclei, an area in which we have become one of the centers of activity in the U.S. Our nuclear-structure laboratory contains 2 electrostatic accelerators—one a conventional Van de Graaff, and the other the first machine of a new type, the so-called Insulating Core Transformer (ICT) (Figure 1). This ICT machine will allow us to excite nuclear reactions with a proton beam of up to 100 microamps at 8,000,000 electron volts when all of its auxiliaries are completed. The heart of our nuclear facility is a modern and sophisticated data-collection and digital recording system. This system utilizes high-resolution γ-ray and particle detectors in coincidence networks to collect multiparameter data for later correlation in the excellent scientific computing center provided us by the Aeronautical Systems Division (AFSC). Our emphasis is presently on reactions yielding isobaric analog states in s-d shell nuclei, the reactions being either proton capture or elastic scattering. A search of the literature will reveal that these s-d shell, isobaric analog states were first discovered here at ARL and are of great value in the testing of models of nuclear structure.

Figure 1. View of 8 MEV-ICT electrostatic accelerator.

Figure 2. ARL 61-cm OPOS telescope at the Sulphur Grove Field Station, Ohio used for the study of the optical properties of orbiting spacecraft.

The final area is the study and exploitation of the sunlight scattered from spacecraft. At a nearby field observatory at the Sulphur Grove Field Station, Ohio, we have a unique telescope for the collection and analysis of the optical signatures of spacecraft to determine their dynamical motions, shape, and surface characteristics. The instrument (shown in Figure 2) will allow characterization of space objects larger than one foot or so in size. This program provides support to other Air Force organizations and to NASA. An example of this is our present monitoring of the performance of flash-discharge lamps on board the GEOS-B geodetic satellite for analysis of possible malfunctions in the onboard computer-control system. This is at the request of the National Geodetic Satellite Program Office, NASA.

Hypersonic Research Laboratory

DR. ROBERT H. KORKEGI, Director

The spectrum of fluid mechanical problem areas relevant to USAF needs is quite broad. Within this spectrum the Hypersonic Research Laboratory has selected and concentrated its efforts on a few key areas, bearing in mind both long-range and more immediate Air Force requirements.

Our five areas of research are as follows:

In aerodynamic stability, we have a theoretical and experimental program of study of stability derivatives in pitch, roll, and yaw—singly and combined—of slender bodies of revolution relevant to ballistic re-entry systems.

Next, we have a study designed to obtain optimum hypersonic vehicle configurations with a view toward providing guidelines to a potential vehicle designer.

A very large part of our research is devoted to flow separation and viscous interactions such as would arise on components of supersonic and hypersonic lifting vehicles, and particularly in inlets of air-breathing engines. Such interactions can result in localized high heating, can affect the performance of controls, and can cause the degradation of inlet flows. We are now directing our viscous-flow studies in two important areas:

(1) Numerical techniques for solving the compressible Navier-Stokes equations.

(2) Experimental research on turbulent shear flows at high Re (order 10^8) toward the simulation of actual flight conditions.

We also have a modest effort in rarefied gas flows with kinetic-theory studies of general relevance to high-altitude flight phenomena.

Finally, we have started an effort in low-speed aerodynamics toward determining aerodynamic characteristics relevant to VTOL (Vertical Takeoff and Landing) vehicles in transition flight between hovering and cruise.

Scientists testing hypersonic shapes in 4-inch vertical wind tunnel.

Solid State Physics Research Laboratory

DONALD C. REYNOLDS, Director

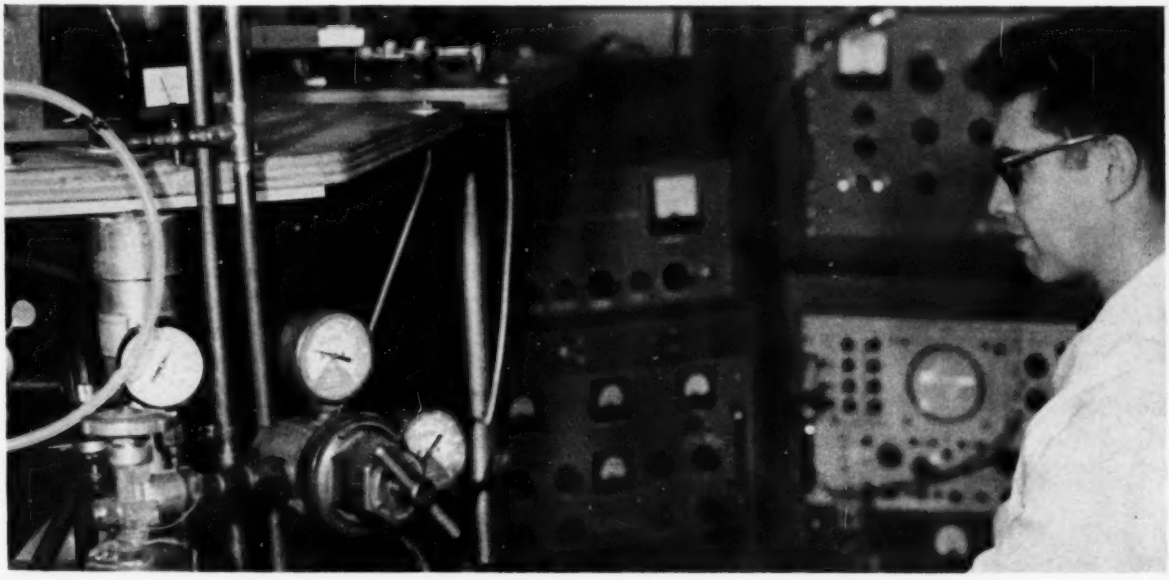
Research in the Solid State Physics Research Laboratory is limited primarily to the area of II-VI compounds. The research is divided into three groups, as follows:

I. Reaction of semiconductors to electron bombardment. This group is engaged in the study of host lattice defects. The tools for the study consist of electron accelerators up to 1 mev in energy. Host lattice defects are created by electron bombardment; these consist of vacancies and interstitials. Optical and electrical phenomena associated with these defects provide a technique for monitoring their creation. By adjusting the electron bombarding energy, the threshold energy for creating defects can be determined. Electron-paramagnetic-resonance studies and nuclear-magnetic-resonance studies are carried on in conjunction with this program.

II. Pressure effects of II-VI compound semiconductors. Research in this group is concerned with both uniaxial and hydrostatic pressures. Both optical and electrical properties of materials are studied. The pressure studies permit one to follow the motion of the electronic energy bands as a function of pressure and thus add to a fundamental understanding of the material. Measurements of bulk compressibility permit one to separate pressure effects from temperature effects when investigations are carried out at different temperatures. The available pressure equipment permits hydrostatic pressure measurements at approximately 30,000 atmospheres at room temperature, and approximately 12,000 atmospheres at 77°K.

III. Research on growth and properties of compound semiconductors. This group engages in research on the growth of crystals, which is again limited primarily to II-VI compound materials. Melt, vapor and solution-type growth are being studied. Crystals are supplied to all of the groups in the Laboratory as well as to many Government laboratories, universities and other laboratories throughout the world. This group also studies many of the optical and magneto-optical properties of the crystals. Much effort is devoted to the study of excitons, both free and bound, in these materials. From these studies many of the basic properties of the materials are determined. Theoretical studies are also carried on in this group. Electronic energy band calculations are being carried out from first principles; the programs are not adjusted to experimental parameters. The theoreticians also collaborate with the experimentalists in interpreting and analyzing experimental results.

The goal of the solid-state program is to understand the materials under investigation fundamentally and to predict practical uses for the materials that may have Air Force application. The number of applications and potential applications of materials is a direct function of the fundamental understanding of the materials.



Conducting electron-paramagnetic-resonance studies at ARL.

Metallurgy and Ceramics Research Laboratory

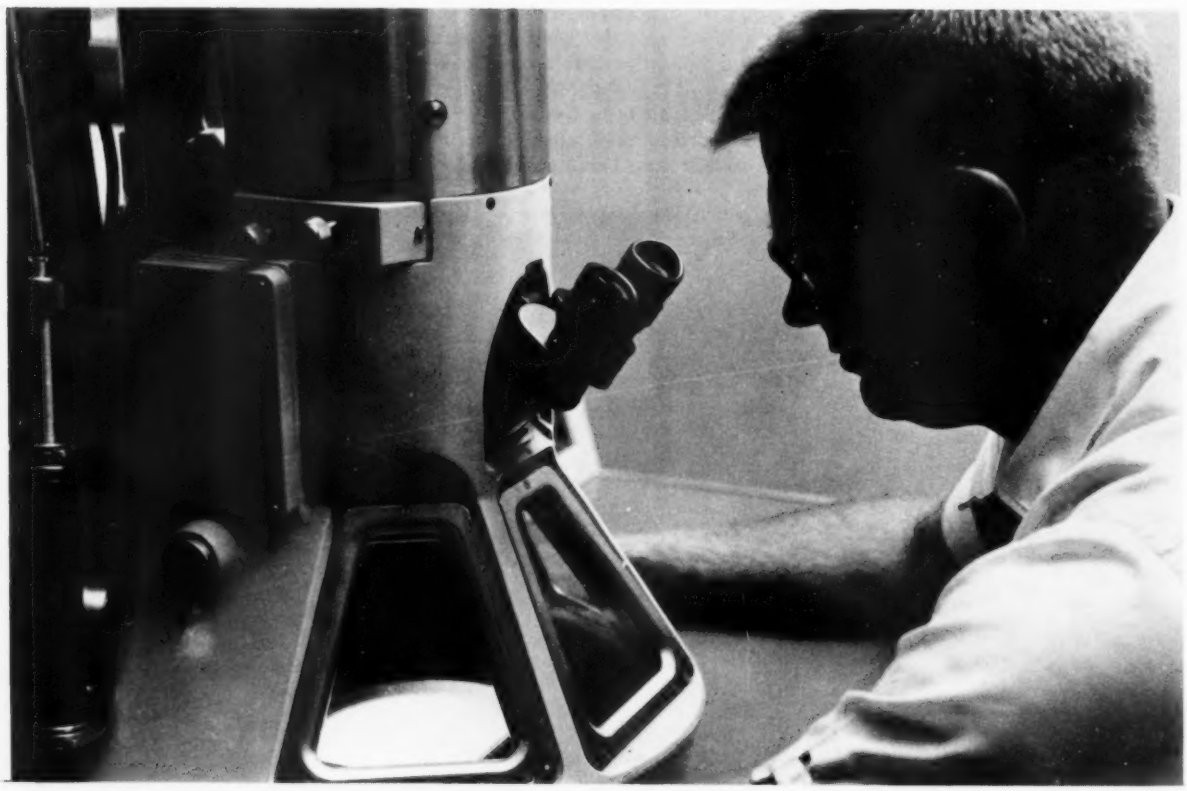
EDWARD J. HASSELL, Director

Our metallurgy research is concerned with the mechanical and strength properties of metals, especially from the atomistic point of view. Studies are currently under way on the mechanism of precipitation hardening, factors controlling the transition from ductile to brittle behavior, the initiation and propagation of cracks, and the mechanism of stress corrosion. The materials studied include stainless steels, aluminum-zinc alloys, and titanium alloys. X-ray techniques and especially transmission electron microscopy are used to evaluate internal structural changes in the test materials.

Our ceramic research concentrates on the determination of the kinds and distribution of the atomic defects present, and the role these defects play in controlling the transport of electricity through the crystal. Experimentally, we determine conductivity (both bulk and surface), polarization, thermoelectric power, weight change (over a range of temperature and oxygen partial pressure), dielectric loss, and capacitance. The materials studied are alumina, scandia, zirconia, oxides of niobium, and complex oxides such as nickel aluminate.

We are also investigating the thermoluminescent properties of some of the rare-earth oxides (erbium oxide and yttrium oxide) for a better understanding of the band structure and the number and types of energy traps present, since this information is related to laser behavior.

Finally, we have a unique capability for studying the mechanism and kinetics of oxidation processes at extremely high temperatures. The objective is to devise methods to improve the oxidation resistance of the materials. The work is done at temperatures up to 4,300°F in controlled oxidizing atmospheres, and by the use of an ultrasensitive microbalance to continuously record the weight change of the material. New materials, including combinations of carbides, nitrides, and oxides developed for possible rocket-nozzle application, are being investigated.



Scientist examining internal structure of specimen with electron microscope.

Introduction to Selected ARL Research Programs

COL PAUL G. ATKINSON, JR., Commander, ARL

Fundamental investigations in relevant areas of Air Force interest typically uncover a network of avenues which lead to possible applications and concepts. At ARL every effort is made to recognize these concepts at an early date, and to give them management visibility. Continued fundamental investigation is almost always indicated. It is necessary also to ask ourselves hard, practical questions, and to frequently seek the answers ourselves in making an assessment of future significance to the Air Force. It is important also not to compromise the continuing efforts of fundamental research.

Short reviews of a selected number of these concepts have been prepared. Some of the concepts are well-matured programs at this time, while others are still embryonic. Coupling efforts appropriate to the present status are under way.

RESEARCH IN MULTICOMPONENT FLOW

MAJ JAMES D. BUTT
Energetics Research Laboratory, ARL

Nearly 10 years ago, shortly after relocating in the new ARL facilities, a fundamental research program on curved, multicomponent aerodynamic flow was initiated. This work, under the direction of Dr. Hans J. P. von Ohain, now Chief Scientist of ARL, was conducted within the Thermomechanics Research Laboratory and, after several years of growth, was one of two projects transferred to ARL's Energetics Research Laboratory which was established in 1966.

The original research concentrated on studying the phenomena of confined vortex flows and, particularly, the causes and effects of the secondary flow patterns of a vortex. The secondary flow, or the flow velocity in a radial and axial direction in contrast to the strong rotational velocity, was found to be always in a direction toward the exhaust opening. Thus, the use of a vortex to separate microscopically sized particles from the carrier gas was severely hindered because the secondary flow would sweep a large portion of the centrifuged particles out the exhaust. If the secondary flow could be reversed, resulting in retention of the particles, a significant increase in the application of vortex or swirl flow devices might be effected.

ARL scientists concluded that the conventional secondary flow resulted from the friction of the gas flow with the chamber walls. To overcome this friction, air was injected in a series of tangential inlets along the cavity walls, particularly near the exhaust opening, as illustrated in Figure 1. As predicted, this caused the secondary flow to reverse—flowing away from the exhaust, along the wall and radially inward at the center of the dual chamber shown. Particles centrifuged by the swirl flow are thus retained in the chamber and recirculated in the vortex; or they can be removed by bleeding a small percentage of the flow out through ports located near the center.

The clear advantage of the reversed secondary flow for particle separation and retention becomes very significant when we look at applications. Basically, the resulting improved separation of smaller particles, better than was possible with conventional vortex devices, made it practicable for ARL to propose a colloidal-core-reactor concept, and to enhance the state-of-the-art in dust separation. This concept is to provide rocket propulsion by means of nuclear energy. Stored liquid hydrogen is vaporized and heated by means of a nuclear-fission reaction in a cavity and expelled through a nozzle to provide thrust. The advantages over chemical-fuel rockets are significant—first, because of the higher temperature, there is a much higher specific impulse, 1,200 to 1,500 sec; and second, there is a high thrust to propulsion-system weight, 10:1 to 20:1, resulting in greater payloads and a significant increase in space maneuverability.

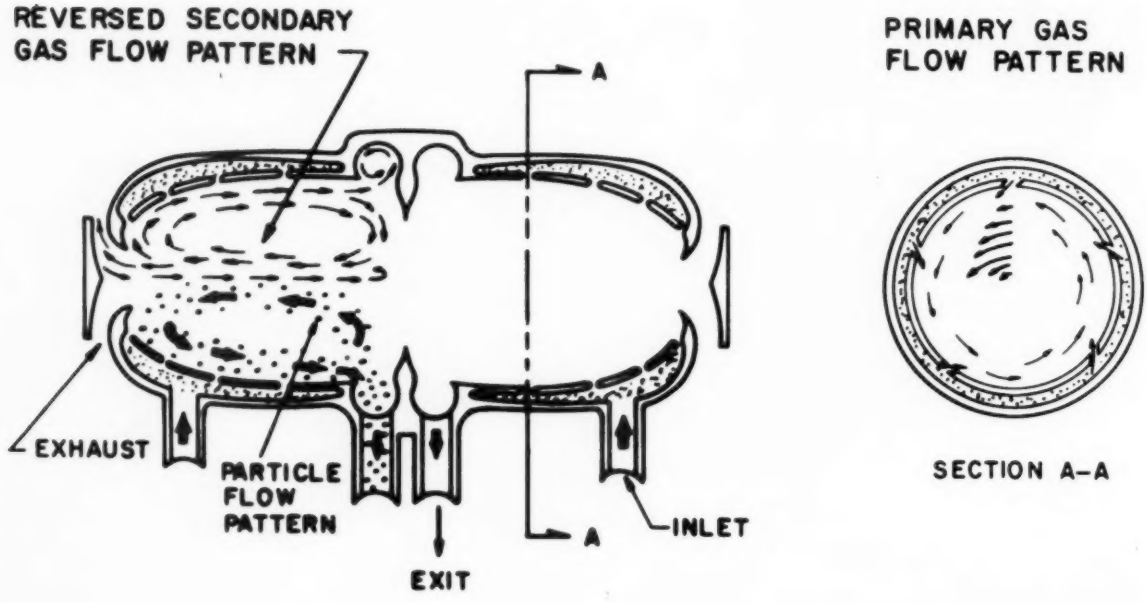


Figure 1. Swirl chamber with reversed secondary flow.

Nuclear rockets are not a new idea. A joint NASA-AEC program has successfully demonstrated a nuclear-rocket system employing a solid core. The colloidal-core concept represents the next step beyond the solid-core reactor because of a higher specific impulse resulting from higher allowable gas temperatures, and the increased thrust-to-weight ratio of the system. The conceptual performance of a colloidal-core-reactor propulsion system makes it suitable for a wide range of cislunar space missions of both a military and exploratory nature.

Figure 2 illustrates one of several possible configurations of a colloidal-core reactor which will help to explain the concept. The cavity is lined with graphite segments to resist the high temperatures. The darkly shaded area represents the berylium reflector required to maintain a sufficient neutron density within the cavity to allow a fissioning chain reaction. A high-strength pressure vessel encloses the reactor.

In operation, liquid hydrogen is pumped through channels in the reflector for cooling, is vaporized, then injected tangentially into the cavity to maintain a swirl flow. The reversed secondary flow retains the uranium-fuel charge of very fine dust particles in the cavity as shown by the dotted areas. The hydrogen gas is heated by the energy of the nuclear reaction and is expanded through the nozzle, providing the thrust.

The most demanding aspect of this concept concerns the aerodynamic flow within the cavity. The gas flow must perform three tasks in interaction with the fuel particles: first, it must retain the particles and prevent them from being swept out through the nozzle; second, the flow must maintain a critically shaped cloud of fuel to preserve the nuclear-fission process; and third, it must prevent stagnation or impact of the fuel on the cavity walls.

The retention or separation aspects are pretty well in hand as a result of our work with reversed secondary flow over the past several years. The other flow requirements are still to be resolved; but we are working and advancing in these areas. In addition to its in-house research on aerodynamic flow problems relating to the colloidal-core-reactor concept, ARL is supporting an external effort with Westinghouse Astronuclear Laboratory. This contract calls for Westinghouse to investigate the variety of nuclear parameters, material requirements, and testing and safety considerations involved with implementation of the concept.

The second program resulting from the initial research on reversed secondary flow is concerned with inertial particle-separation studies, the results of which are being applied to the problems of turbine-engine protection and air-pollution control. Credit for initiating and encouraging

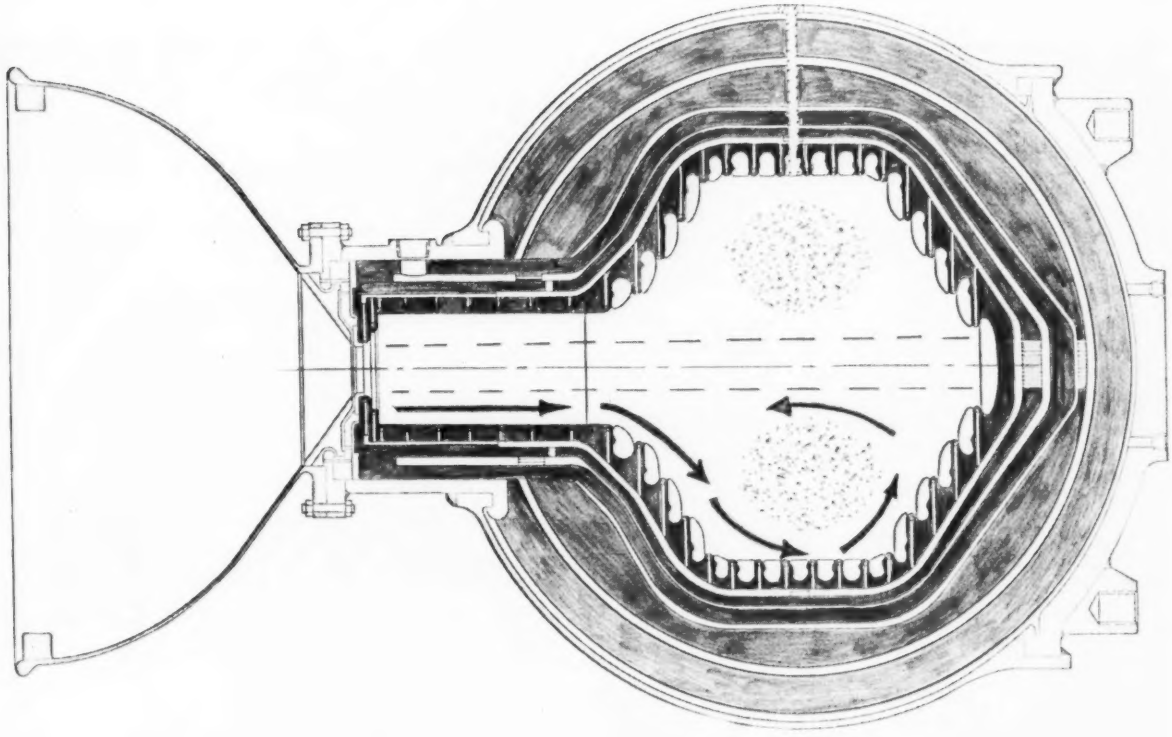


Figure 2. Colloidal-core nuclear reactor.

our program on dust separators must be given to the Army. About four years ago, ARL was approached by the Army Tank and Automotive Command with a requirement for a very-high-efficiency dust separator to protect a future gas-turbine-powered tank. They had heard of our research with vortex separators and thought it might be applicable to their program.

Experience in Vietnam had shown that a gas-turbine engine has a very low tolerance for dust ingestion before the engine fails or needs an early replacement. ARL thus agreed to expand its research work into low-pressure-ratio dust separators applicable to the Army's requirements, and the Army partially funded the program with $175,000.00 over a 3-year period.

In addition to its support of Army requirements, ARL has coupled with helicopter-systems-project offices on engine dust protection, and has held several briefings for industry on its work with dust separators for engine protection and air-pollution control. The following is a brief review of the evolution and applications of dust separators.

Figure 3 is a picture of the first ARL dust separator. It is, in many respects, similar to the chamber shown in Figure 1; but its bulk, weight, and low flow capacity make it unsuitable for most applications.

By greatly improving its designs, but still using a reversed-flow principle, ARL devised a separator of individual units clustered together for increased capacity. Figure 4 shows the first clustered separator mounted on an Army jeep, which was powered by a small experimental gas-turbine engine. The jeep was tested under heavy-dust conditions at the Army's Proving Grounds in Arizona. It survived more than four hours of this testing, with no damage to the engine; however, a similar but unprotected engine failed after only a few minutes in the heavy dust.

Next, as shown in Figure 5, a cluster of 46 smaller units was built and tested. With a flow capacity approximately equal to that of the jeep cluster, this separator has only 20% of the bulk and a higher separation efficiency. The 46-unit cluster separator was also tested by the Navy for the separation of salt spray, with excellent results.

ARL has also designed a separator system for the Air Force runway sweeper as shown in Figure 6. A prototype of this sweeper will soon be tested, and results are expected to prove the superiority of the ARL separator over the cloth dust bags which are currently used.

Finally, ARL is co-operating with the Air Force Logistics Command at Wright-Patterson AFB to determine the feasibility of using ARL separator designs for removing fly ash from power-plant-stack gases. An architect-engineer study to determine feasibility and design a prototype system is presently in procurement channels. In this work ARL has coupled with the Public Health Service which has expressed considerable interest and suggested the possibility of its actively seeking further applications of the ARL separators to the National Air-Pollution-Control Program.

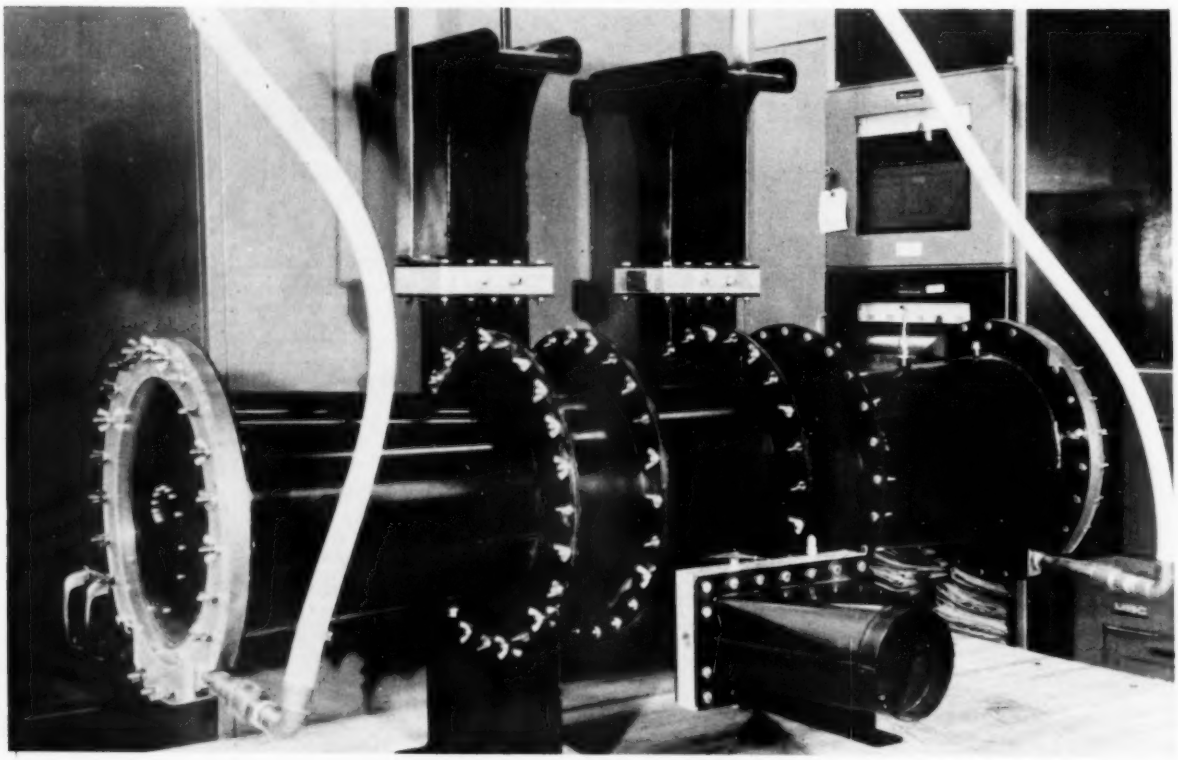
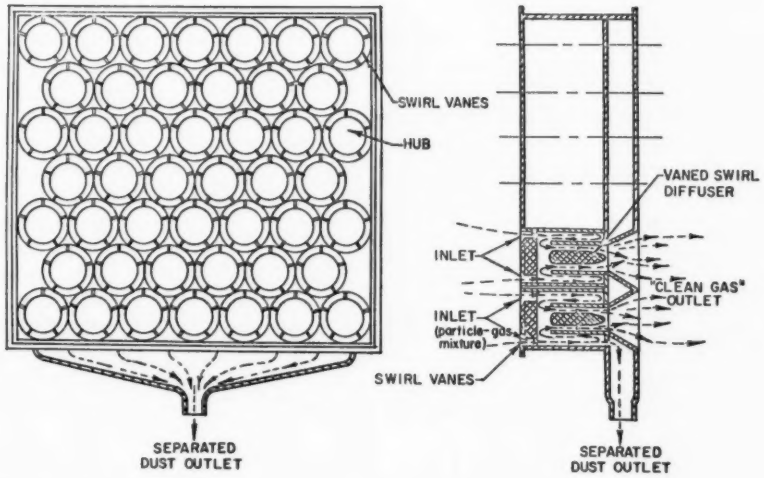


Figure 3. First ARL dust separator.

Figure 4. First clustered separator mounted on turbine-powered Army jeep.

Figure 5. Schematic of a 46-unit cluster separator showing the general flow paths.



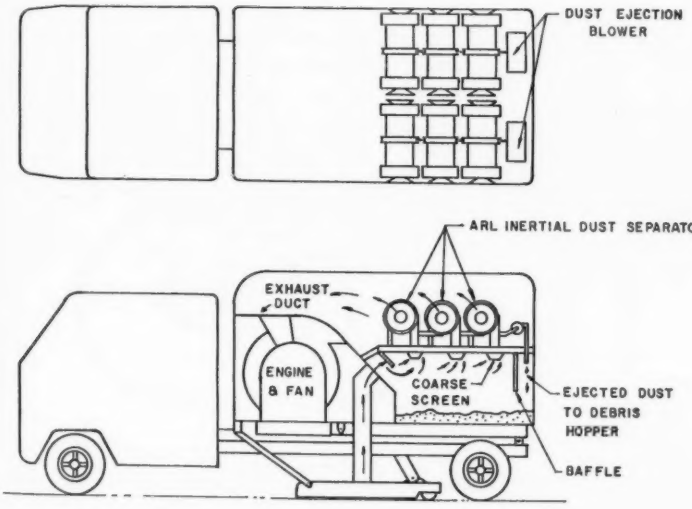


Figure 6. Runway sweeper using ARL inertial separators.

electrofluid-dynamic energy conversion

MAURICE O. LAWSON
Energetics Research Laboratory, ARL

The electrofluid-dynamic energy-conversion research program is being conducted at ARL's Energetics Research Laboratory. Electrofluid-dynamic energy conversion, or EFD, is a process whereby fluid power is converted directly into electrical power without moving parts (Figure 1). The EFD process can be compared with a Van de Graaff

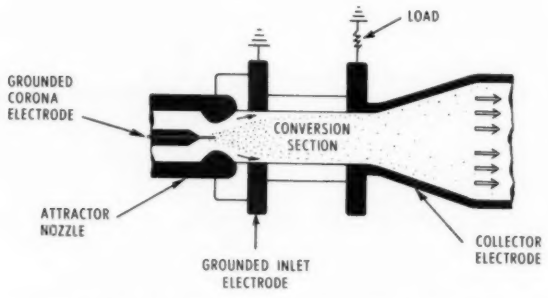


Figure 1. EFD generator process (fluid-dynamic Van de Graaff).

generator in which the moving belt is replaced by a flowing gas, which is also nonconductive. Unipolar charges, i.e., charges of one sign only, are formed in the gas to the left of the grounded inlet electrode (as shown here by a corona process), and are carried by viscous forces through the insulator conversion section against the retarding electric field of the collector which is at a high potential. The charges are collected on the wall and, from there, the current passes through the load.

This process differs from the well-known magneto-hydrodynamics process in that only electrical fields are used; its power characteristics also differ in that very high voltages and low current densities are produced. Further, the process operates from room gas temperatures up to thermal ionization levels; hence, it is suited for closed-cycle as well as open-cycle operation.

The first objective of ARL's research program was to determine similarity and scaling laws. During this research phase, two major problem areas became evident which greatly handicapped the application of EFD in the field of direct conversion from heat into electrical energy.

The first of these is that the total-pressure ratio of EFD

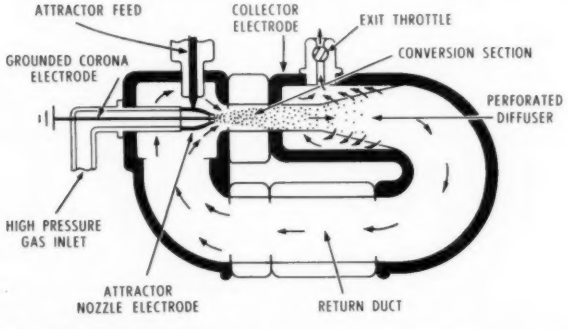


Figure 2. Recirculatory EFD generator, schematic view (closed-cycle simulation).

processes is inherently small—which, for efficient operation, requires low subsonic velocities. This is inconsistent with thermodynamic cycles having favorable conversion efficiencies from heat into fluid-dynamic energy, and which require high-expansion pressure ratios corresponding to supersonic velocities. A major application concept was generated for alleviating this handicap, corresponding to a recirculatory ejector process. In this ejector process, the Mach number of the flow from the nozzle is supersonic, consistent with the thermodynamic-cycle requirements, while the Mach number of the flow in the EFD conversion section is subsonic, consistent with the low-pressure ratio characteristic of the EFD process (Figure 2). A gas chosen for favorable EFD properties circulates in the large-diameter continuous duct producing electrical power in the top portion of the path. In the ideal case, a high-molecular-weight vapor is chosen for the thermodynamic cycle, and enters through the high-pressure gas inlet. The molecular weight is sufficiently high in comparison to that of the EFD gas so that, upon expansion through the nozzle to supersonic Mach numbers, its velocity (because of its corresponding low speed of sound) is only on the order of twice that of the EFD gas. This condition provides favorable energy transfer from the vapor to the gas.

The second problem area with regard to application is that, in order to operate in the lower part of the EFD voltage spectrum—on the order of 100,000 volts—very-small-diameter channels must be used. This is because of space charge effects. The similarity and scaling investigations revealed that the hydraulic diameter is a characteristic parameter for the electrical as well as for the fluid-dynamics process. Whereas the circular channel of small diameter can handle only small mass flows and is therefore extremely power limited, a small-hydraulic-diameter channel having a cross section corresponding to a long narrow slot can be of large area, and can therefore handle high mass flows of high kinetic powers.

In Figure 3 the two application concepts have been integrated and are shown schematically in the form of a radial outflow geometry. The vertical dashed line indicates the axis of symmetry. The primary flow enters along the axis and is ideally a high-molecular-weight vapor. The low subsonic recirculating EFD gas enters about the nozzle body, and the two fluids flow radially outward through the conversion channel to the collector. The radial geometry is very favorable from a manufacturing standpoint, and also for staging to achieve still higher power, since stages would be side by side on a common axis. Thus there would be the most effective use of the volume of a pressure container having the form of a cylinder.

The in-house research on similarity and scaling laws has been completed, with excellent agreement between theory and experiments having been achieved. The design of a radial-outflow conversion test apparatus has also been finished, and experimental investigations are now just beginning.

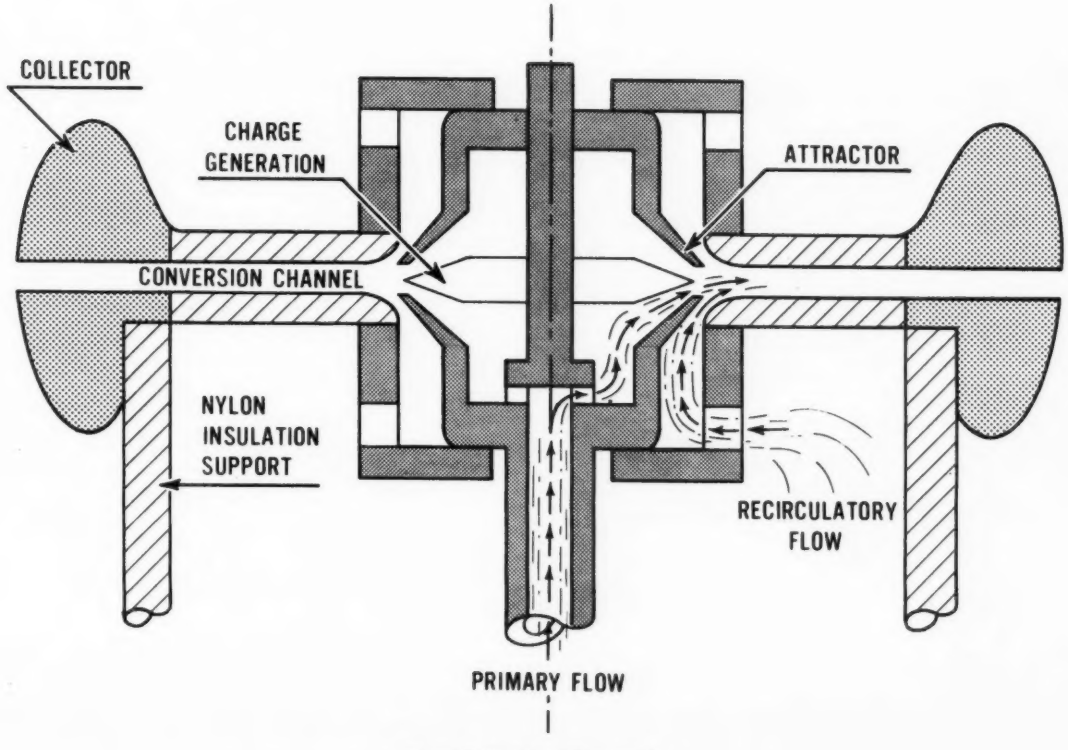


Figure 3. Radial-outflow nozzle.

CADMIUM-SULFIDE INVESTIGATIONS

DONALD C. REYNOLDS
Solid State Physics
Research Laboratory, ARL

One of the early programs in the Solid State Physics Research Laboratory was an investigation of materials for high-temperature diodes. This program led to the development of the CdS solar cell, which now is approaching the application stage. The cell is a thin-film configuration consisting of evaporated CdS on a plastic substrate. The barrier layer is produced by plating Cu_2S over the CdS film. The Cu_2S is of a high-conductivity P-type material, and the CdS film is of a high-conductivity N-type material.

A model proposed by Shiozawa has been quite successful in explaining many of the experimental details of the CdS cell. This model assumes a composite layer structure as shown in Figure 1. The Cu_2S layer is very thin ($\sim 0.5\mu$), and is strongly P-type. Absorption measurements on this material made by Eisenmann, Sorokin, et al, and Marshall and Mitra indicate that it is an indirect material. A composite plot of their measurements, after Shiozawa, is shown in Figure 2. A plot of α (absorption coefficient) as a function of λ (wavelength) is shown in Figure 3. Four linear regions are observed, indicating two indirect transitions at 1.2 eV and 1.8 eV. These correspond closely to the photovoltaic peaks at 1.8 eV and 1.3 eV observed by Grimmeiss and Memming. The Cu_2S layer makes an ohmic or near-ohmic contact to Cu-diffused intrinsic CdS. The photovoltaic barrier is formed between intrinsic CdS and strongly N-type CdS. Gold is used to contact the P-type Cu_2S, and Zn forms an ohmic contact to N-type CdS.

The model assumes that essentially all of the light is absorbed in the Cu_2S. From Figure 2 it is seen that light less energetic than 1.2 eV will not be absorbed in the Cu_2S layer. It will likewise not be absorbed in CdS and, as a result, will not be used by the cell. This energy conforms closely with the long wavelength limit of response of the cell.

Since Cu_2S is an indirect semiconductor, the absorption coefficient for photons with energy greater than 1.2 eV will rise rather slowly with increasing photon energy. This property of the absorption coefficient, coupled with the extreme thinness of the layer, allows some of the photons with energies between 1.2 eV and 2.4 eV to penetrate to the intrinsic CdS region. These photons will produce photoconductivity in the intrinsic region, thus reducing the series resistance.

The electron-hole pairs are primarily created in the Cu_2S layer and are created nearer the surface for the more energetic photons. The electrons are the minority carriers in the Cu_2S layer and must diffuse to the intrinsic CdS region. The dominant barrier field occurs between the intrinsic CdS and the strong N-type CdS. There is likely, however, an appreciable electric field across the intrinsic CdS layer under illumination due to the concentration gradient of diffused copper acceptors in this layer. Once the electrons enter the intrinsic CdS region they would be influenced by this field, and would migrate by a combination of both diffusion and drift. They would thus be driven to the space charge barrier region where they would be accelerated into the N-type CdS region and into the ohmic zinc contact. As the electrons move to the zinc electrode, a corresponding number of holes will move to the gold electrode, which makes ohmic contact with the CU_2S layer.

Experience with materials such as silicon and germanium, which are indirect band-gap materials, suggests that, for a given quality of crystal, the minority carrier lifetime is greater for the indirect band-gap material than for

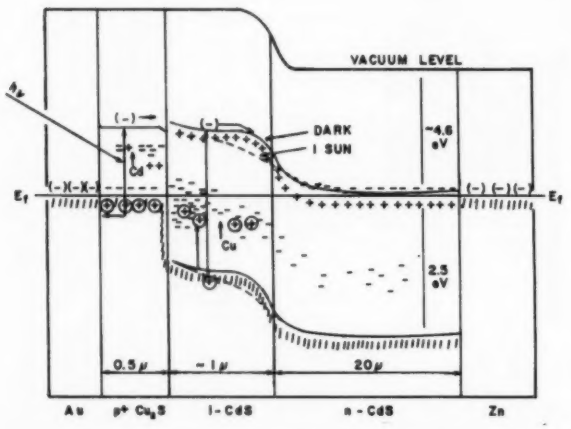


Figure 1. Energy model for CdS thin-film cell.

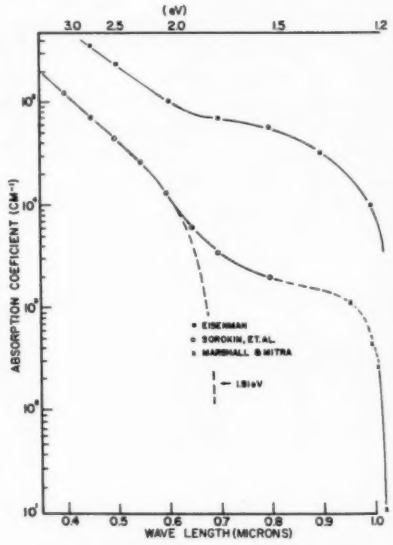


Figure 2. A composite plot of the absorption coefficient as a function of wavelength for Cu_2S. The data were compiled from several sources.

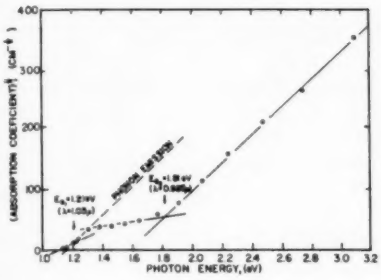


Figure 3. A plot of the square root of the absorption coefficient, from Figure 2, as a function of photon energy.

the direct band-gap material. This would indicate a *reasonable* lifetime for electrons in Cu_2S, and thus the diffusion of photogenerated electrons through the Cu_2S region to the barrier would not be unreasonable.

The decrease in the film-cell response at photon energies greater than 2.4 eV would be expected from this model since they would be absorbed near the surface and the generated electron-hole pairs would experience a higher recombination rate. The surface recombination will be influenced by free carrier densities in excess of equilibrium values and by surface states.

The above model proposes a junction between intrinsic CdS and N-type CdS. The cells are heated to approximately 250°C in the process of preparation. This will cause Cu to diffuse a short distance into the CdS from the Cu_2S layer. In this diffused region, the Cu centers will compensate the donors. The Cu level is approximately 1.4 eV below the conduction band in CdS. The Fermi level in this intrinsic region will be close to the Cu level. In the N-type CdS region, the Fermi level is close to the bottom of the conduction band. The diffusion of electrons from the N-type region into the intrinsic region establishes at equilibrium a potential barrier equal to $E_{fn} - E_{fi}$ approximately equal to 1.4 eV. E_{fn} represents the Fermi level in the N-type region, and E_{fi} is the Fermi level in the intrinsic region. The open-circuit voltage of the cell is approximately half the barrier height so that it can be readily accounted for by this model. The model successfully explains the experimentally observed characteristics of the film cells.

Orbital-flight tests and balloon-flight tests are currently being made on the cells. Due to their flexibility, light weight, radiation resistance and low cost, they have great potential for auxiliary-power sources for both balloons and satellites.

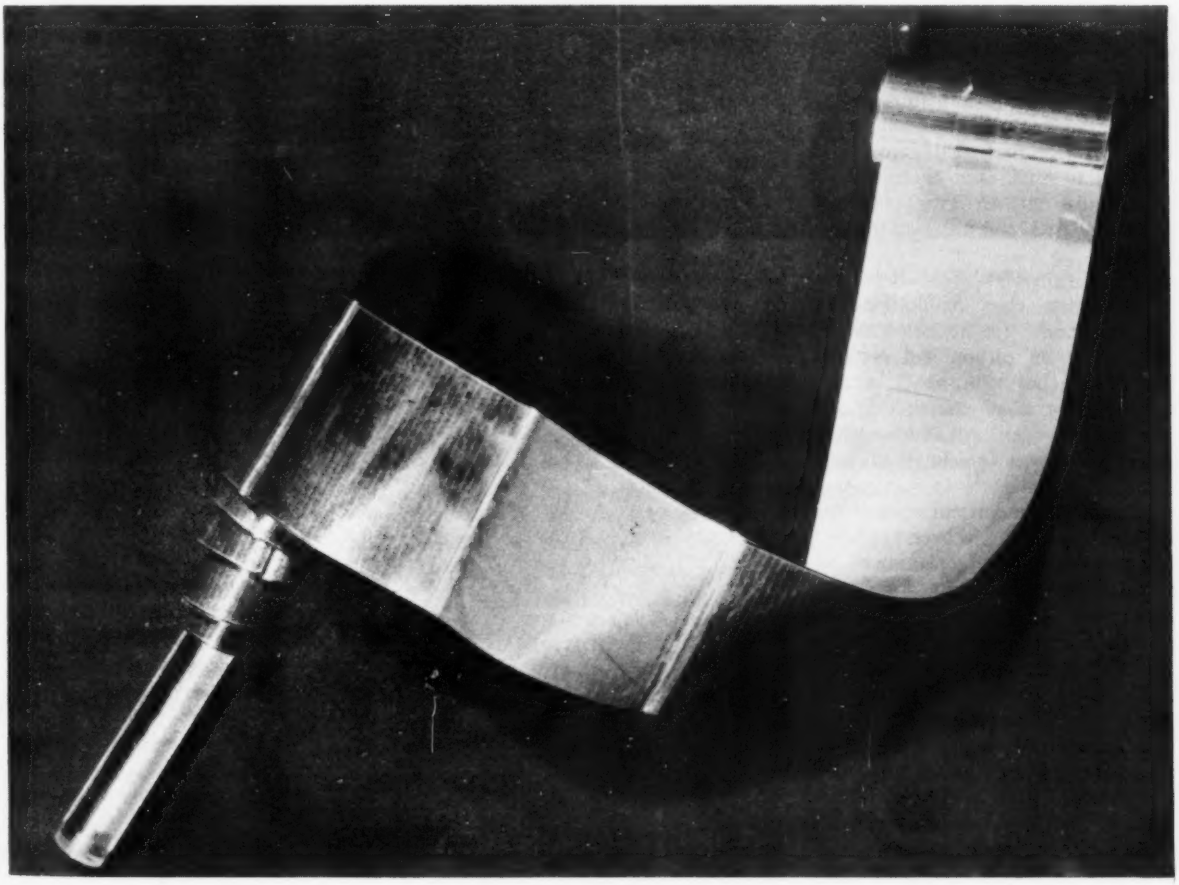


Figure 4. Sample of flexible thin-film cells.

perchlorocarbons

DR. LEONARD SPIALTER
Chemistry Research Laboratory
ARL

ARL's perchlorocarbon program reflects fulfillment of the entire gamut of activities and responsibilities included within ARL's mission.

In 1961 a Spanish chemist, Prof. Manuel Ballester of the University of Barcelona, Spain, with some interesting and theory-challenging ideas, was invited to spend one year at ARL to permit his concepts to mature and to become familiar with the goals of the Chemistry Research Laboratory. He returned to Spain and continued his work under an Air Force contract funded by ARL and managed through EOAR.

Prof. Ballester's goal was to develop a new class of compounds, "chlorocarbons" (as he called them), based only on carbon and chlorine atoms. This class is formally related to hydrocarbons, which contain only carbon and hydrogen, and which are the parent substances for almost all nonmetallic materials.

Based on the current state of the art and theory, it had been predicted that the complete replacement of hydrogen by chlorine would either be impossible, or that any resulting perchlorocarbons–(where the prefix, per, indicates full chlorine substitution)–would be inherently unstable and fall apart. The problem is exemplified in Figure 1, where the sixfold greater volume of chlorine compared to hydrogen in the scale molecular models of perchlorotoluene and toluene, respectively, is shown to create considerable atom-to-atom strain. Nevertheless, Prof. Ballester did

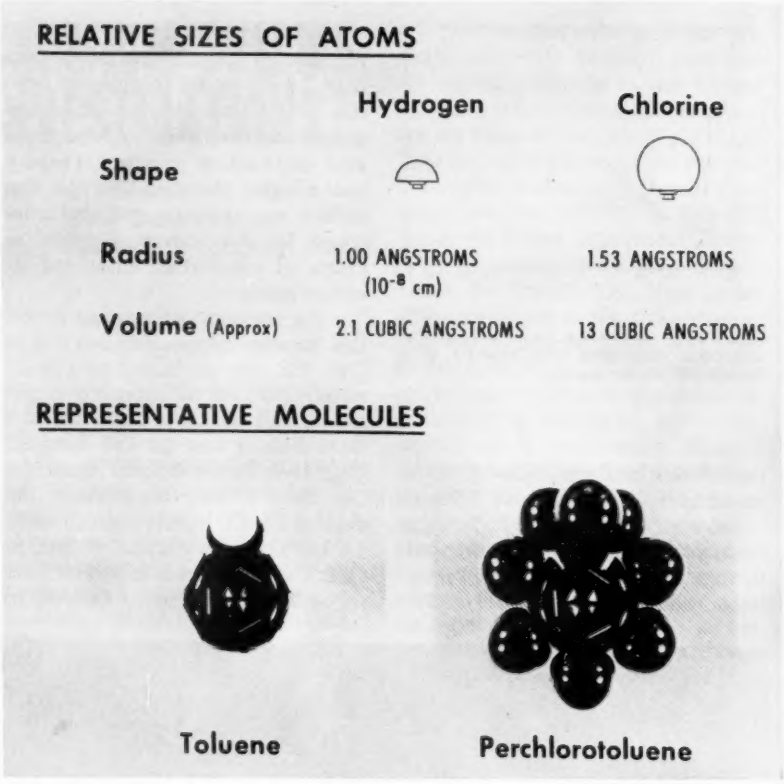


Figure 1.

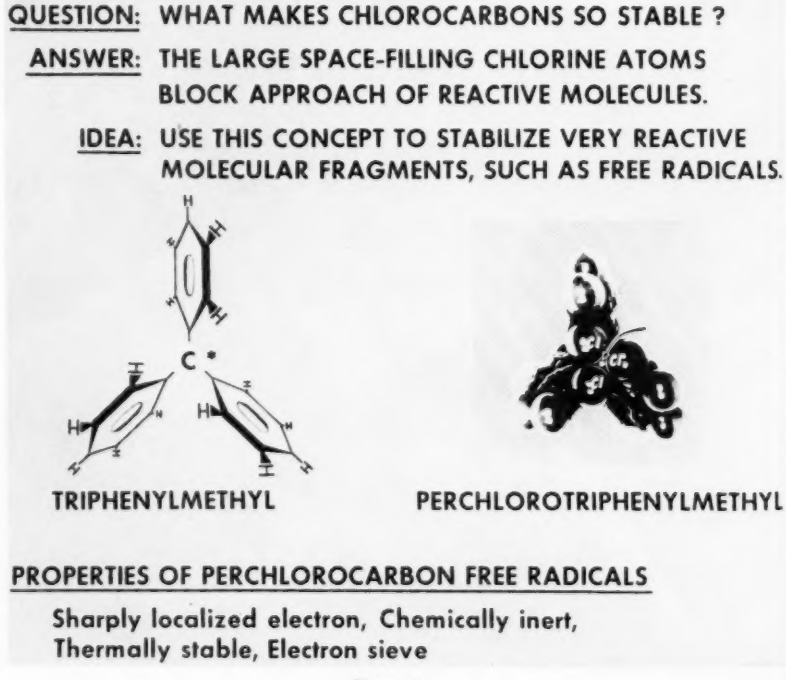

QUESTION: WHAT MAKES CHLOROCARBONS SO STABLE ?
ANSWER: THE LARGE SPACE-FILLING CHLORINE ATOMS BLOCK APPROACH OF REACTIVE MOLECULES.
IDEA: USE THIS CONCEPT TO STABILIZE VERY REACTIVE MOLECULAR FRAGMENTS, SUCH AS FREE RADICALS.
TRIPHENYLMETHYL
PERCHLOROTRIPHENYLMETHYL
PROPERTIES OF PERCHLOROCARBON FREE RADICALS
Sharply localized electron, Chemically inert,
Thermally stable, Electron sieve

Figure 2.

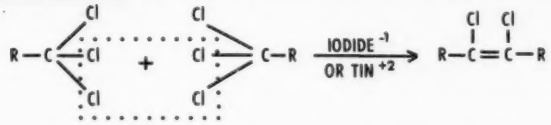
successfully discover a unique specialized composition of aluminum chloride ($AlCl_3$), sulfur monochloride (S_2Cl_2), and sulfuryl chloride (SO_2Cl_2) which was powerful enough to effect perchlorination but selective enough not to break down any resulting products or intermediates.

The resulting perchlorocarbons proved, by and large, to be much more stable, both chemically and thermally, than predicted. For example, many were unaffected by temperatures above 500°C in air, and some survived 600 hours of boiling with fuming nitric acid. The source of this surprising stability, where observed, was attributable to the large bulk of the chlorine atoms which both cushioned the molecule as well as shielded it from the close-enough approach of reactive molecules which could cause a breakdown and the formation of new products. This principle has been applied to free radicals, such as triphenylmethyl, where the central carbon does not have its normal stable complement of four bonds, but has a single odd electron which avidly reacts with other molecules like itself, and with oxygen in the air, chlorine, nitrogen oxides, and other common species. The perchlorinated analog, Figure 2, inaugurated a new class of inert, free radicals whose large space-filling chlorine atoms excluded reaction with other molecules. Only electrons, under normal conditions, have been able to penetrate this barrier and to reach the central, free-radical site. This offers the promise of producing electron-active organic substances.

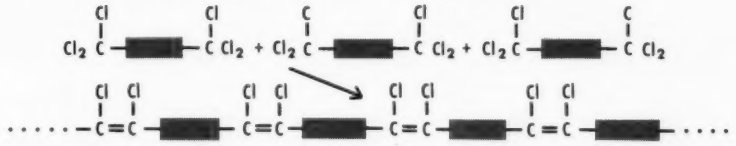
One requirement for utility in chemical systems is the ability to form polymers or macromolecules. These large and long molecules are the raw materials for plastics, adhesives, lubricants, fibers, sealants, elastomers, etc. Although perchlorocarbons are usually unreactive, the presence of $-CCl_3$ groups has been found to provide a route to double the size of, and even to polymerize, these substances (Figure 3). Tin compounds and iodine have been found to join two such separate trichloromethyl groups by -CCl=CCl- bonds with the removal of four chlorine atoms. The resulting larger molecules also show the characteristic stability of the perchlorocarbons.

PROBLEM: POLYMERIZATION; HOW TO BUILD BIG MACRO MOLECULES FROM THE SMALL USUALLY INERT CHLOROCARBONS.

BALLESTER DISCOVERY: A UNIQUE REDUCTIVE CONDENSATION



ANSWER: USE ABOVE REACTION WITH DOUBLE ENDED MOLECULES TO MAKE LONG CHAINS.



RESULT: MANY DIFFERENT BIG MOLECULES (POLYMERS) WITH STABLE PROPERTIES OF PERCHLOROCARBONS.

Figure 3.

PERCHLOROCARBON RESEARCH RESUME
(100% OAR - SPONSORED)

PAPERS PUBLISHED - 29 (13 SPANISH, 8 U.S., 6 INTERNATIONAL, 1 BRITISH, 1 FRENCH)

PATENTS AND APPLICATIONS - 9 (3 SPANISH, 3 U.S., 3 CANADIAN)

MAJOR FINDINGS -

a. INAUGURATION AND DEVELOPMENT OF PERCHLOROCARBON CHEMISTRY
b. MOST POWERFUL SELECTIVE CHLORINATING AGENT KNOWN
c. SPECIFIC CONDENSATION - POLYMERIZATION REACTION
d. HUNDREDS OF CHLOROCARBONS
e. NEW METHOD OF CHLORINE ANALYSIS IN ORGANIC MOLECULES
f. NEW TYPE OF THERMOCHROMISM (TEMPERATURE-INDUCED COLORS)
g. COMPOUNDS COLORED BECAUSE OF MOLECULAR DISTORTION
h. NEW QUANTITATIVE LAW RELATING COLOR AND STRUCTURE
j. PREPARATION OF STABLE POLYMERIC CHLOROCARBONS
k. FIRST INERT FREE RADICALS
l. FIRST STABLE CHARGED CHLOROCARBON FRAGMENTS
m. FIRST MAGNETIC POLYMER
n. MORE THAN TWENTY (20) NEW ORGANIC REACTIONS

TOTAL (9 yrs) 18 PERSONNEL - $118.5K

THIS YEAR 12 PERSONNEL - $14.1K

Figure 4.

The results and significant features of the Ballester fundamental research program have been impressive (Figure 4). However, a requirement still existed for exploring the commercial applicability of the concept so as to hasten the transition to developmental activity. To this end, after much com-

petitive bidding, a "research-exploitation" contract was let two years ago to the Dow Chemical Company. Since that time, Dow has made significant strides (Figure 5) towards verifying, on a large scale, the earlier research results and proving out the potential of perchlorocarbons. More important, their screening procedures have suggested other new Air Force applications and further developmental possibilities, particularly in lubricants, fluids, and electronic materials. As hoped for in the initial concept of the research-exploitation contract, the contractor is now sufficiently motivated to invest his own financial and manpower resources in this exciting new area. Other Air Force and commercial organizations have also now begun to show an active interest in exploiting the perchlorocarbons for practical end products. The potential applications suggested (Figure 6) are indeed exciting. Even if only a few are realized, they will have justified ARL's participation in, and guidance of, the perchlorocarbon research program.

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PERCHLOROCARBON RESEARCH EXPLOITATION RESUME

(Dow Contract)

MAJOR FINDINGS:

a. Larger Scale Validation of Ballester's Research Results.

b. Improved Syntheses. (20 x Efficiency)

c. New Polymerization Technique.

d. New Properties Discovered:

Extreme pressure additive to oils.
Favorable biological activity.
Nonflammable wide-liquid range fluids.

TOTAL (2 yrs) - $120K
THIS YEAR - $ 60K

Figure 5.

SOME POTENTIAL APPLICATIONS OF CHLOROCARBONS

1. **THERMOSTABLE AND INERT SUBSTANCES**
   Lubricants, Dielectrics, Plastics, Fibers, Tank liners, ...

2. **SPECIALIZED ADDITIVES**
   Fireproofing, Plasticizing, ...

3. **MAGNETIC AND ELECTROMAGNETIC DEVICES**
   Field calibration, Frequency standards, Timers, ...

4. **LIGHT-WEIGHT ELECTRONIC AND ELECTRICAL EQPMT**
   All-plastic batteries, Energy converters, Organic transistors, ...

5. **INTEGRATED MULTI-PROPERTY COMPONENTS**
   Organic metal paints, Computer memory units, Radar-spoofing, ...

6. **IMPROVED ADHESIVES**
   Plastics-to-metal welding, Metal fiber composites, ...

Figure 6.

volatile rare-earth chelates

DR. CHARLES S. SPRINGER, JR.
Chemistry Research Laboratory, ARL

In the past few years, a good deal of research has been conducted at ARL, under the direction of Drs. Robert E. Sievers and Ross W. Moshier, on volatile metal chelates. (1) Figure 1 depicts a portion of the periodic table indicating some of the metals which have been successfully investigated. This article concentrates entirely on the group of metallic elements called the rare earths. (2) This includes the lanthanide metals, i.e., lanthanum (La) through lutetium (Lu), as well as scandium (Sc) and yttrium (Y) which so often occur with the lanthanides in nature.

The name "rare earth" is somewhat of a misnomer since many of the elements are not particularly rare and, in fact, are more abundant than some of the more common elements found in the earth's crust. They are, however, very difficult to separate from one another due to their almost identical chemical properties. The best separation methods currently in use in the chemical industry still take months to obtain sufficient amounts of samples of suitable purity. Thus the cost of obtaining pure compounds bears no relationship to their abundance, and may have inhibited extensive research on this class of compounds. Despite the slow progress in the past, some interesting uses of rare-earth compounds have been found, for example, the use of europium compounds as red phosphors in television and oscilloscope screens, the use of rare-earth oxides as extremely efficient catalysts in the cracking of petroleum fractions, and the employment of terbium and europium compounds in potential laser developments.

Upon surveying the problem of separating chemical compounds, one is struck with the number of techniques which are available if the compounds

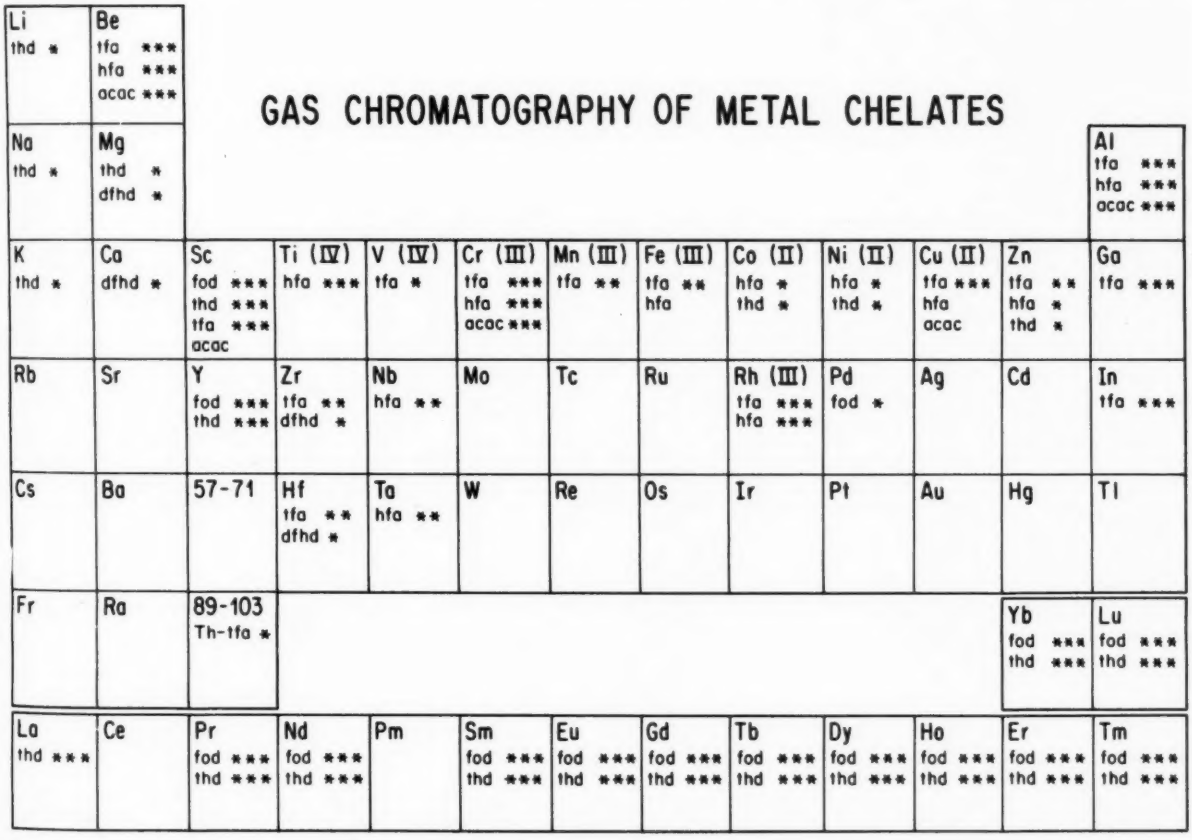


Figure 1. The metallic area of the periodic table. The symbolic code letters in the various elemental blocks indicate particular volatile compounds which have been investigated.

exhibit volatility. The quantitative significance of the adjective "volatile" is somewhat nebulous but, in this article, a compound will be considered "volatile" if it exhibits a vapor pressure of at least 1 mm Hg at temperatures easily attained in the average chemical laboratory. The common forms of the metallic elements, i.e., the pure metals and ionic salts, do not attain such vapor pressures until their temperatures reach thousands of degrees centigrade. Therefore, they are relatively intractable to techniques requiring volatility. However, there is a class of metal compounds which do have the property of volatility to some degree. These are called the "inner complexes" and compose a subclass of a larger group called "coordination compounds." Figure 2 shows a typical example of the types of inner complexes which have been investigated at ARL. Such compounds are called chelates because of the presence of rings containing the metal ion. These chelates of the rare-earth metal ions can have vapor pressures of ~1 mm Hg at temperatures less than 200°C in some cases. Their volatility may be attributed to a number of factors. In large part, it is considered to be due to their lack of electrical charge. In the example given, a metal +3 cation is surrounded by three -1, β-diketonate organic anions. A second contributing factor is illustrated in the photograph of molecular models of these kinds of compounds shown in Figure 3. The polar parts of the molecule, the metal and oxygen atoms, are well shielded in the center of the complex by the peripheral sheath of nonpolar carbon and hydrogen atoms. Thus the molecular aggregates are held together by weak Van der Waals forces of attraction rather than by the strong electrostatic forces usually present in metallic compounds, conferring on them properties resembling those of organic compounds.

The techniques commonly used to separate volatile organic compounds now become amenable to use with the volatile metal chelates. These include the following three methods:

Distillation – Some exploratory work has begun at ARL and is meeting with a degree of success.

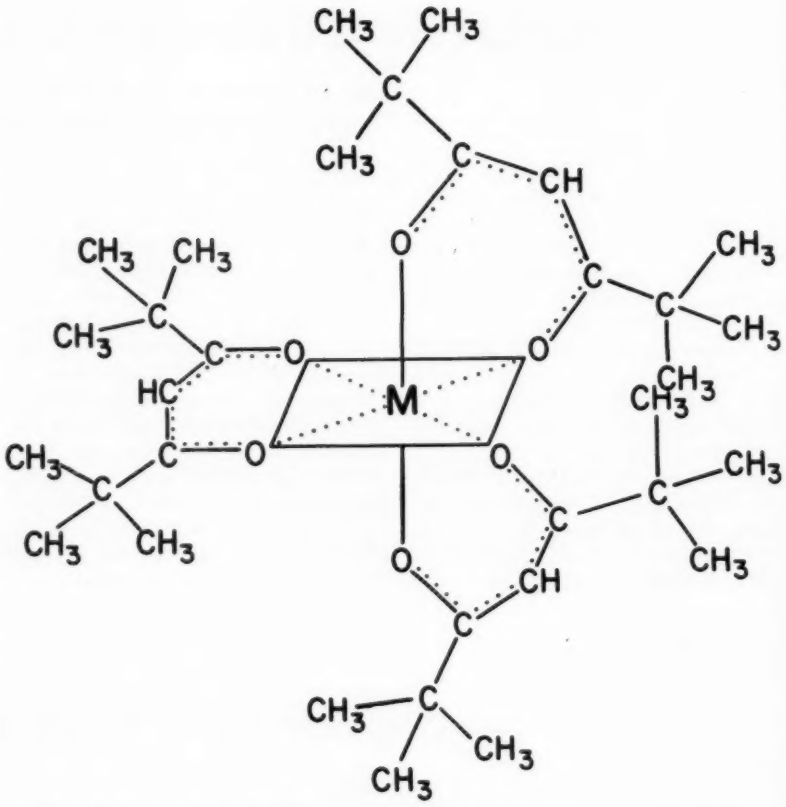


Figure 2. The possible octahedral structure of a tris (2,2,6,6-tetramethyl-3,5-heptanedionato) chelate of a trivalent rare-earth- metal ion (M^{3+}).

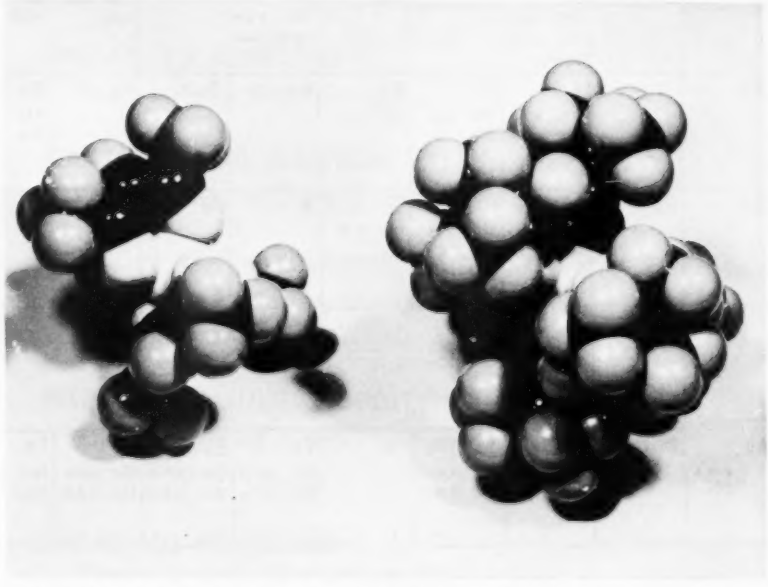


Figure 3. Molecular models of tris(acetylacetonato) (left) and tris(tetramethylheptanedionato) (right) chelates of +3 metal ions.

Gas Chromatography – Much more work has been done with this technique. A simplified schematic diagram of a gas chromatograph is shown in Figure 4. The sample, consisting of a mixture of the components to be separated, is injected into the heated port and conveyed by a carrier gas into a thermostatted column where the actual separation takes place. The separated components are then detected and revealed as individual peaks on the strip-chart recorder. A typical chromatogram is shown in Figure 5. This shows 4 different rare-earth compounds completely separated from each other in less than 20 minutes.

Sublimation – This technique has also been studied rather extensively. A simplified schematic drawing of a fractional sublimer constructed at ARL by Mr. D. R. Locker is shown in Figure 6. It consists of a brass tube lined with glass. The brass tube is heated evenly by a current passing through it, but a wrapping of insulated nichrome wire superimposes a thermal gradient along the two tubes, with temperature decreasing from left to right. A carrier gas of helium is directed through the tube from left to right and the sample, which is again a mixture of components, is placed in the hot zone of the tube. As the sample vaporizes, the helium carries the components toward the cooler regions. The less-volatile compounds condense on the walls before the more volatile complexes, and are thus sepa-

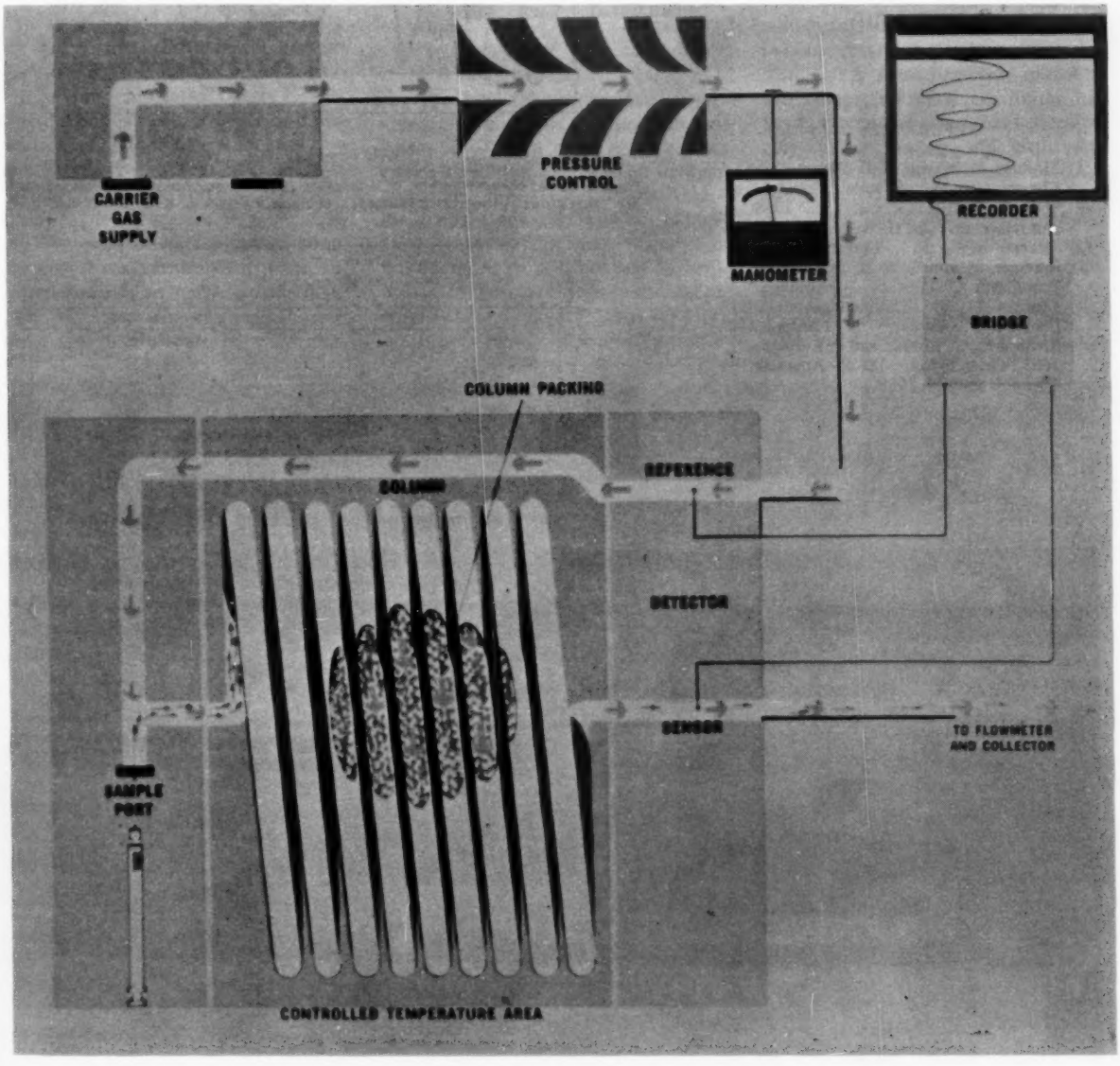


Figure 4. A simple schematic drawing of a gas chromatograph.

rated. The results of such an experiment with a mixture of a lanthanum and terbium compound are shown in Figure 7. Under irradiation by visible light (upper), two distinct white areas are seen in the tube, indicating separation. Upon irradiation by UV light (lower), only the terbium compound (right) is seen to fluoresce in a blue-green color. The terbium compound is more volatile and has moved farther down towards the cold regions of the tube than the nonfluorescent lanthanum complex. The transitions giving rise to the fluorescence are the lasing transitions of Tb(III).

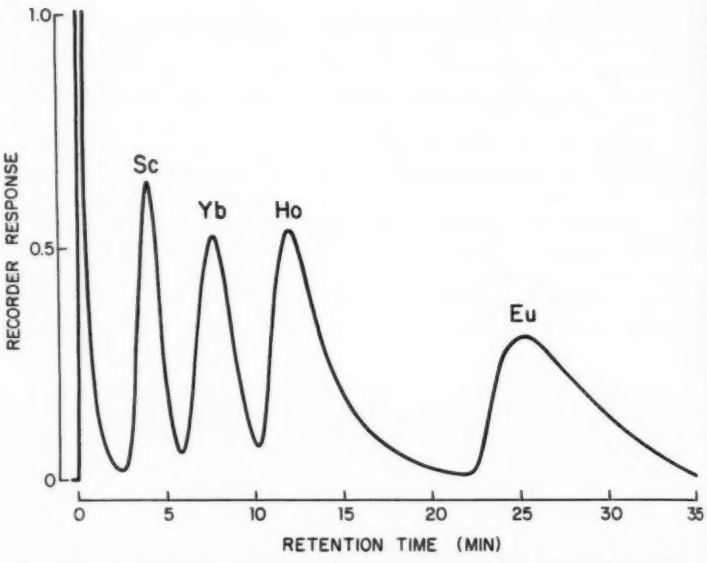
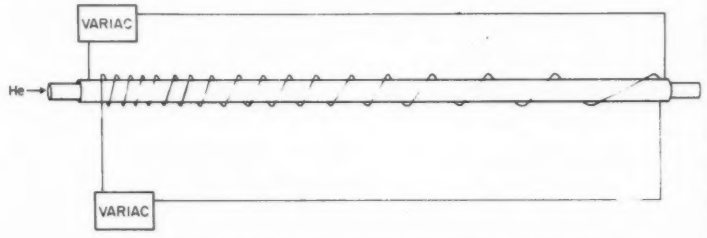


Figure 5. A chromatogram of scandium, ytterbium, holmium, and europium tris (tetramethylheptanedionato) chelates. (Work of K. J. Eisentraut)



THERMAL GRADIENT SUBLIMATION APPARATUS

Figure 6. A simplified schematic diagram of a fractional sublimer.

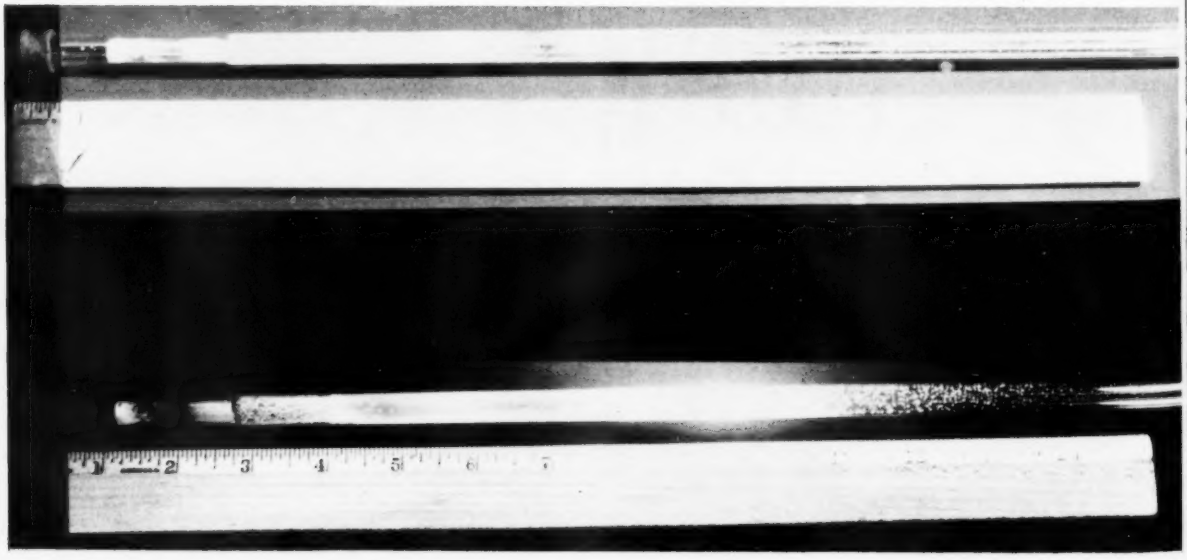


Figure 7. The results of a fractional sublimation of lanthanum and terbium tetramethyl heptanedionato complexes. (Work of K. J. Eisentraut)

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blunt-trailing-edge supersonic compressor

DR. ARTHUR J. WENNERSTROM
Fluid Dynamics Facilities Research Laboratory, ARL

The blunt-trailing-edge supersonic-compressor program concerns high-speed axial compressors of the sort used in jet engines and certain other gas turbines. Figure 1 shows a typical contemporary jet engine where each of the numerous rows of blades represents a compressor stage.

A supersonic-axial-compressor stage is one in which the flow velocity within the compressor exceeds the speed of sound relative to one or more blade rows. This is independent of the vehicle velocity which may be anything from zero to supersonic, depending upon the application.

Our interest in supersonic compressors arises because their potential performance is so much greater than that of more conventional, lower-speed designs. However, to realize this potential, some formidable problems in fluid mechanics must first be understood, and then solved.

Figure 2 illustrates a hypothetical jet engine employing a supersonic-compressor stage. Success in this research could lead to the development of simpler, lighter, and more compact engines having far fewer compressor stages than present-day engines.

The kind of performance we are aiming for is a stage pressure ratio in excess of 3 at a stage efficiency in excess of 82 percent coupled with an acceptably low stage discharge velocity. I might add that this last parameter, the stage discharge velocity, is quite important. It is not too difficult today to design a high-performance stage having a high-discharge velocity; but it is extremely difficult to produce one which can be successfully mated to the other components constituting an engine.

Figure 3 illustrates the blunt-trailing-edge configuration which is a particular configuration of a compressor blade which ARL has been investigating.

ARL's program, conducted by the Fluid Dynamics Facilities Research Laboratory, consists essentially of three efforts. First there is the in-house program which has consisted of the design and theoretical analysis of supersonic stages and experiments with supersonic cascades. Plans for an in-house rotating rig are just now being formulated. A mathematical model of the compressor flow conditions has been prepared; this has aided considerably in correlating and explaining some of the experimental data. A two-dimensional supersonic cascade is now operational, and a test program is under way to evaluate the results of several geometric changes to the compressor blading.

The second effort, funded by ARL, is a cooperative one with the

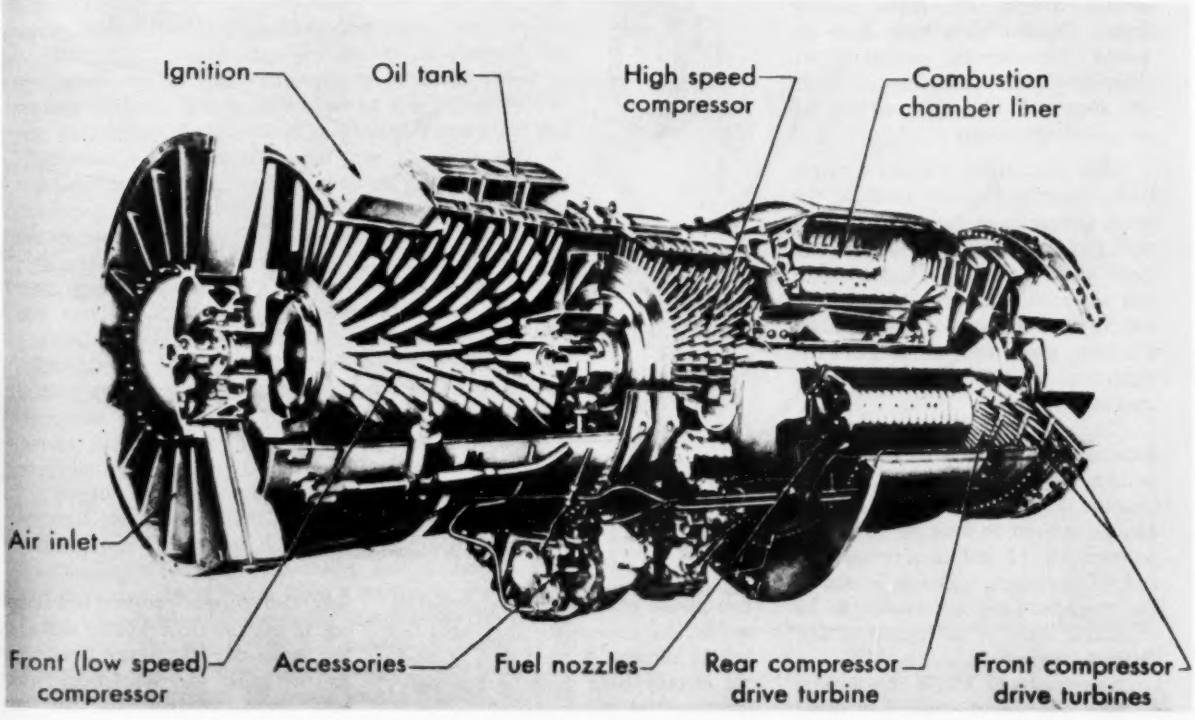

Figure 1. Typical contemporary jet engine.

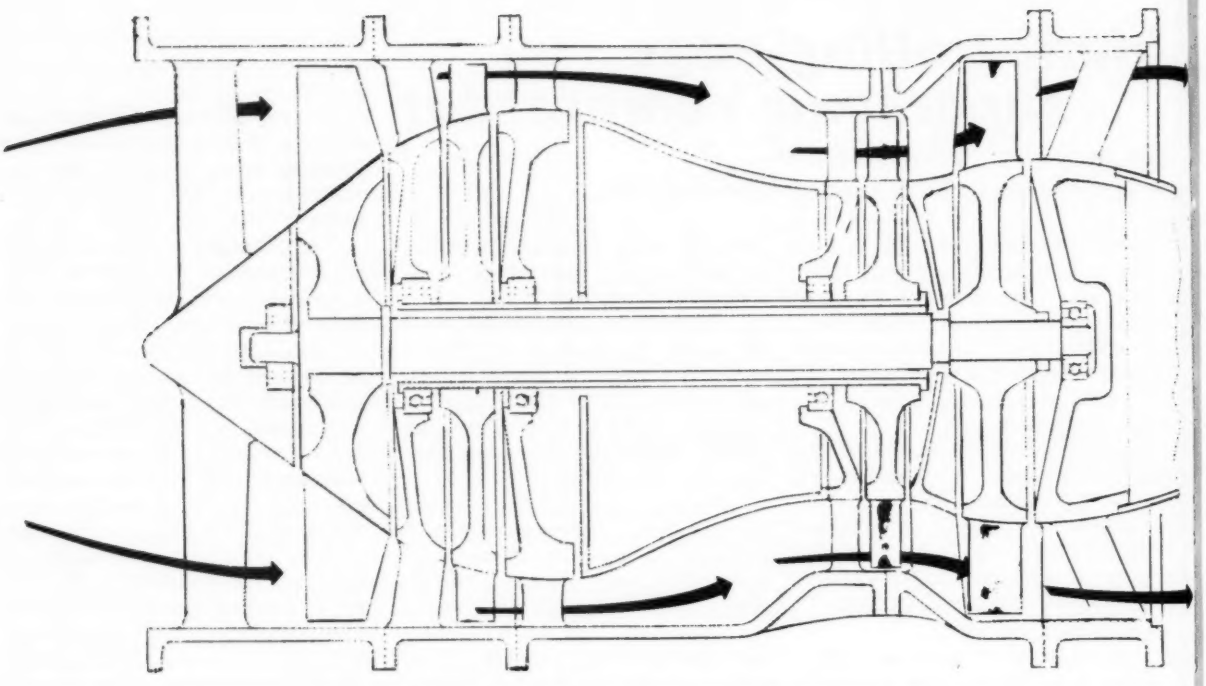

Figure 2. Hypothetical jet engine with supersonic-compressor stage.

Arnold Engineering Development Center, AFSC, through which ARL's compressor designs are experimentally tested. Detailed data have been obtained from several configurations; these have enabled some specific problem areas to be identified and have led to some improvements.

The third effort is under contract with the von Karman Institute for Fluid Dynamics in Belgium. The contract includes the design, analysis, and experimental testing of compressors and cascades. The investigators have completed a number of cascade tests, and have tested two compressor configurations to date with some significant progress.

One of the coupling activities associated with this program was an industry briefing held at ARL in October 1967. The briefing sparked enough interest to draw 40 attendees, representing 12 industrial companies and 4 Government agencies. Several of the manufacturers are known to be exploiting some of the results of our research program.

The results of ARL's experiments to date, and also the results of other investigators, have implied that a positive means of boundary-layer control within the compressor may hold the key to success. A great deal of work has already been done on boundary-layer control, but practically none in conjunction with supersonic compressors. Our current program is attempting to exploit these known means on the supersonic compressor in an effort to overcome the limitations which have been characteristic of past designs.

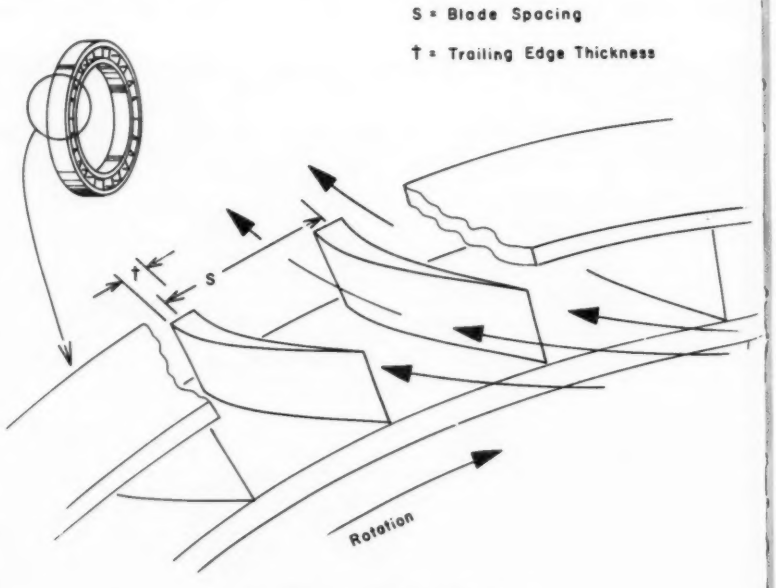

Figure 3. Blunt-trailing-edge blading.

THE HIGH-PRESSURE ARC

LT COL DONALD E. DYE, Thermomechanics Research Laboratory, ARL

In September 1966 it was decided that the Thermomechanics Research Laboratory of ARL should undertake a research program on high-pressure-arc technology. The motivation for this decision was twofold: first, to extend our fundamental knowledge of high-temperature plasmas into the realm of extremely high pressure; and second, to produce engineering-type data for the design and development of high-pressure-arc devices.

The intense radiation from high-pressure plasmas of noble gases and high atomic weights affords many interesting and relevant engineering applications for the Air Force. Some of these applications, for instance, are high-intensity radiation sources for battlefield illumination, standard spectral sources, and radiation-driven simulation facilities. In this last category, one study has shown that the ground simulation of planetary re-entry heat loads would require radiation sources capable of producing 15 KW/cm^2 over a model nose diameter of about 2 inches. The actual maximum heat flux possible with current arc technology is limited to about 9 KW/cm^2.

Figure 1 shows the major phases of the planned research program. The major objective of this research effort is listed as Item No. 1. In addition, before the primary objective can be realized, topics listed as 2 through 5 must be investigated, in conjunction with others and with theory, some of which is yet to be developed.

The ARL high-pressure-arc facility is planned for operations up to 1,000 atmospheres pressure. The conceptual study of this facility required approximately one year before final designs could be selected. Fabrication and installation require one additional year. Therefore ARL, in cooperation with the Systems Research Laboratories, has developed a low-cost facility for operations up to 200 atmospheres pressure. This has allowed the Laboratory personnel to begin experimentation within a reasonable time, and to also conduct the preliminary testing of arcs and components without subjecting the more expensive 1,000-atmosphere components to unknown hazards. The ARL 1,000-atmosphere system is unique in that long-time testing or steady-state experiments can be accomplished. Arcs have been obtained in pressures up to 1,000 atmospheres; however, these have all been pulsed, uncooled and short-time experiments.

Figure 2 shows the total radiation of an argon plasma at constant temperatures, as a function of the ambient pressure up to a pressure greater than 100 atmospheres. Essentially, this figure illustrates that a desired total radiation may be obtained from a particular arc and at a lower temperature by increasing the pressure of the gas surrounding the arc. Although it cannot be illustrated on this simple graph through proper design as shown here, the arc source can also be made much smaller than an equivalent arc at one atmosphere pressure. This is an ideal situation, for instance, for the design of a very-high-

HIGH PRESSURE ARC RESEARCH PROGRAM

MAJOR PHASES

1. **High Pressure, High Temperature Gas Properties.**
2. **System Energy Balances.**
3. **Electrical Characteristics.**
4. **Electrode Design and Attrition Studies.**
5. **Column Motion in High Pressure Environment and Effects of External Magnetic Fields.**

Figure 1. High-pressure-arc research program.

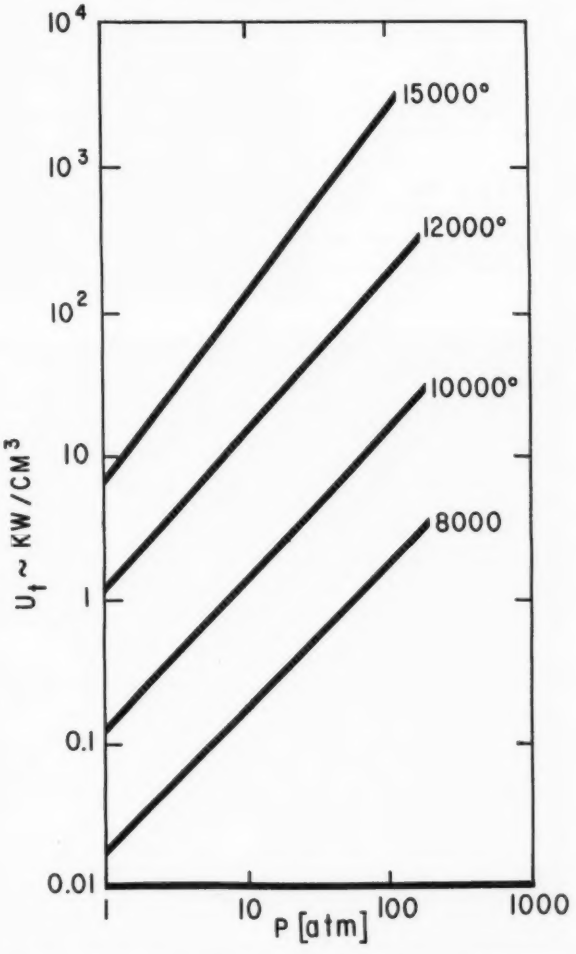

Figure 2. Total radiation of an argon plasma at constant temperatures.

intensity radiation-simulation facility.

Figure 3 shows a 5-mm cascade arc being installed in our 200-atmosphere facility. This particular arc was selected for our first studies because of the well-known boundary conditions and arc characteristics at a pressure of 1 atmosphere. The arc has been under ARL-supported development for several years at Dr. Maecker's institute in Germany.

Figure 4 shows the over-all experimental configuration at ARL. Spectrographic, remote control, and other instrumentation are installed behind the protective wall shown to the right in the illustration. This was necessary because of the personnel hazards involved in working with the high-pressure equipment. Experiments to date have shown that the normally stable arc becomes unstable at about seven atmospheres pressure. We are now involved in redesigning the electrodes and trying different configurations to obtain stability above this pressure.

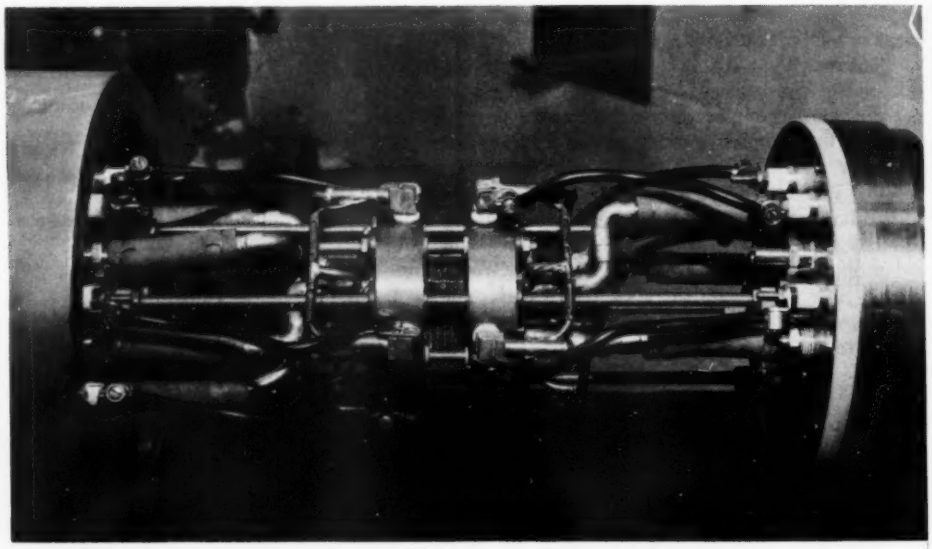

Figure 3. 5-mm cascade arc.

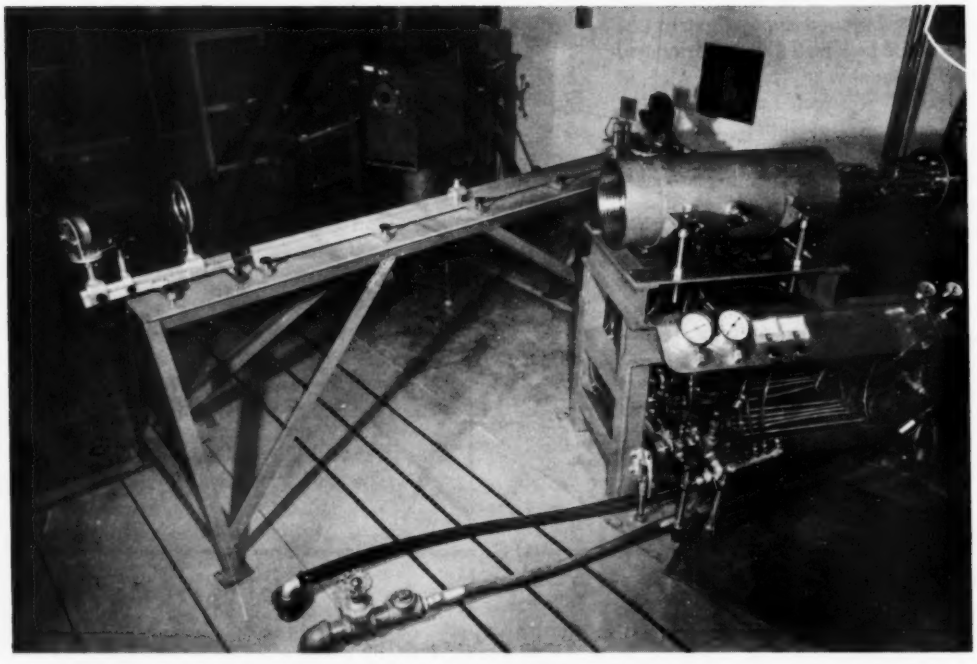

Figure 4. Over-all experiment configuration.

LT COL RICHARD C. WINGERSON, Plasma Physics Research Laboratory, ARL

high-temperature plasma research

At the 5th OSR Symposium on Advanced Propulsion Concepts held in Chicago in April 1968, Dr. Amasa Bishop, director of the AEC-controlled nuclear-fusion program, predicted that we would have the knowledge to build a power-producing controlled-fusion reactor by 1978.

Controlled nuclear fusion has the potential for giving us a high-performance propulsion or power unit, particularly for space applications. The forecast availability date coincides very well with the time the Air Force can be expected to consider a major deployment into space to conduct intercept, inspection, and logistics missions. Thus, it is essential that the Air Force participate actively in the fusion-research area so as to assure compatibility with Air Force requirements.

Controlled-nuclear-fusion research has shown steady progress in the past few years. The Air Force has long supported work in this area. A program at the Aerojet General Corporation leapfrogged the AEC programs to exploit a new concept. This work is several years ahead of comparable AEC efforts and is expected to make a major contribution to the control of plasma instabilities and the achievement of high plasma densities at very-high fusion temperatures.

More recently, we have been directed to review the potential of the fusion research area. As a result, efforts are now being made to explore an area almost completely neglected by AEC, namely, plasma behavior in the presence of strong magnetic and electric fields. A contract was initiated with Electro Optical Systems a year ago, and in-house work is now being conducted from both the theoretical and experimental sides. We expect to make progress along a path from modest plasma densities and temperatures toward the fusion regime.

The concept for our in-house experiment is based on a cylindrical magnetoplasma generated in two coaxial regions with a large voltage applied radially between them. This causes particles to loop inward, achieving high energies suitable for fusion near the center and being retarded to low energy near the outside. Detailed analysis of the system suggests that it may have advantages over present AEC concepts. It should be more stable, have better containment, make more efficient use of the magnetic field, and simplify plasma heating.

Our initial experiments are rather modest, since we are seeking only to confirm theory and establish scaling laws. Complementary theoretical work in the Applied Mathematics, General Physics, and Thermomechanics Research Laboratories of ARL will provide further insight into this concept.

If current predictions are verified, then the only instabilities arising should take the form of surface waves. An attempt will be made to suppress these instabilities by means of interaction with a dynamic electrical structure imbedded in the vacuum chamber walls.

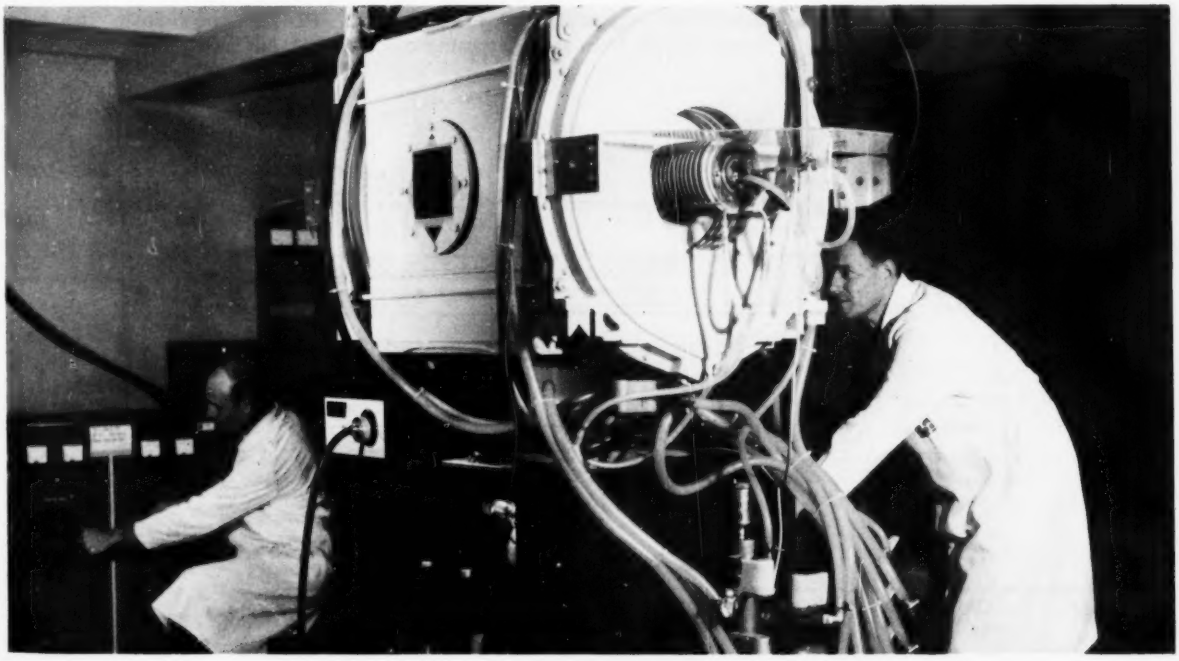

Figure 1. High-temperature plasma-research test equipment

Low-Light-Level Television

DR. BERNARD A. KULP
Solid State Physics Research Laboratory, ARL

In the 1950's our predecessor, the Flight Research Laboratory at Wright Field, was involved in a low-light-level TV project called "Cat-Eye." During the course of that work a philosophy of TV pickup called the isocon was discovered. Figure 1 shows the schematic arrangement of the tube. The pickup tube is quite similar, geometrically, to the orthicon. The mechanism of video signal generation, however, is different. Both the orthicon and the isocon have an "image" section which consists of a photocathode (a material which emits electrons when illuminated) and an insulating target. Electrons emitted from the photocathode are accelerated to several hundred volts and are focused on the target. They "kick out" three to five secondary electrons from the target. Thus, a positive-charge pattern is generated on the target that is a replica of the optical pattern focused on the photocathode. This charge pattern transfers to the reverse side of the target. It is then read and erased by a scanning electron beam.

In the orthicon, the electron beam approaches the target perpendicularly, turns around, and returns to the electron gun where it is collected in an electron multiplier. The video signal is the "ac" component of the beam. That is to say, the video signal is the original beam current minus the current necessary to erase the charge pattern. Now the beam must be intense enough to erase the most positive area of the target. The noise in the output is then determined by this beam current, and not by the video signal level. This limits the dynamic response of the tube.

In the isocon tube the beam "reads" the target as it is parallel to it.

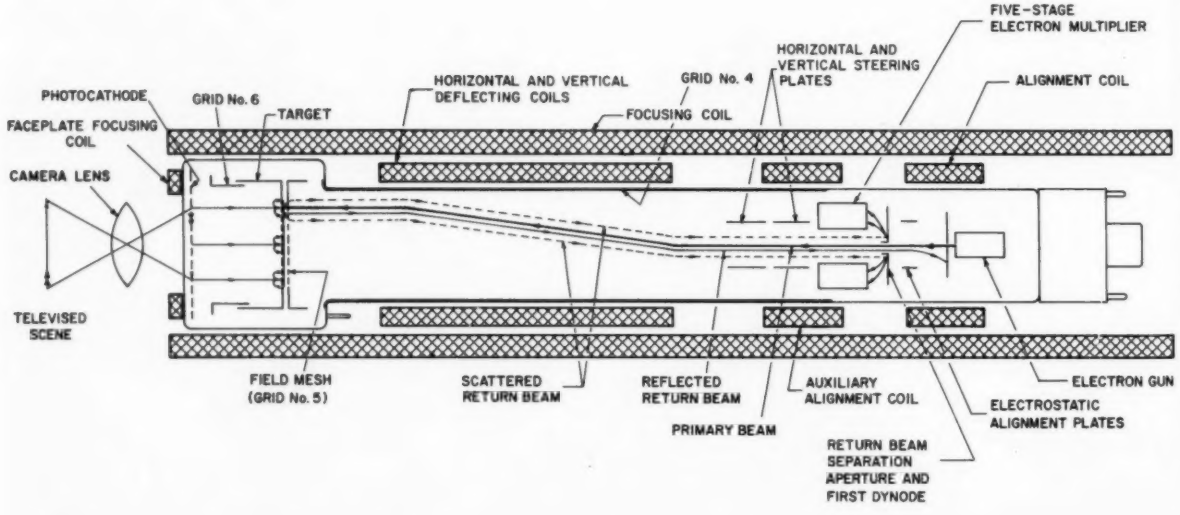

Figure 1. Schematic arrangement of image isocon tube.

Under this condition two or three electrons are scattered out of the main electron beam as the charge pattern is erased. The main electron-beam component in the return beam is caught and grounded, and the scattered electrons are allowed to enter the multiplier and form the video signal. Thus, the noise in the output is a function of the video signal and is essentially independent of the main-beam current. This results in a wide dynamic range with a minimum of signal noise. The use of an electronically conducting glass target of commercial quality and relatively low resistivity results in a very-high-quality image and a high speed of response.

Figure 2 shows a photograph of the fiber optic faceplate isocon tube. Several tubes have been made with S-20 photocathodes and fiber optic faceplates which have 1,000 TV line resolution at 5×10^{-3} foot-candles illumination, and with less than 10 percent residual charge left on the target after the first frame at this light level. Typically, less than 40 percent of the charge remains after the first frame at 10^{-5} foot-candles illumination. This is almost as fast as the secondary electron-conductivity vidicon. The isocon tubes are also characterized by a very high modulation transfer function—typically, 65 percent at 400 TV lines at 2×10^{-3} foot candles on the photocathode.

Figure 3 shows the amplitude response of the fiber optic faceplate image isocon. This makes them excellent for use in high-resolution systems where low-contrast scenes are to be observed. The isocon TV pickup tube has been flight-tested at Eglin AFB under the program managed by ARL. The flight tests have been considered successful. The isocon is relatively easy to make with the use of essentially the same production techniques as for the orthicon. For production in small numbers, the cost should be on the order of $5000 for each and, in large numbers, $3500 or less for each.

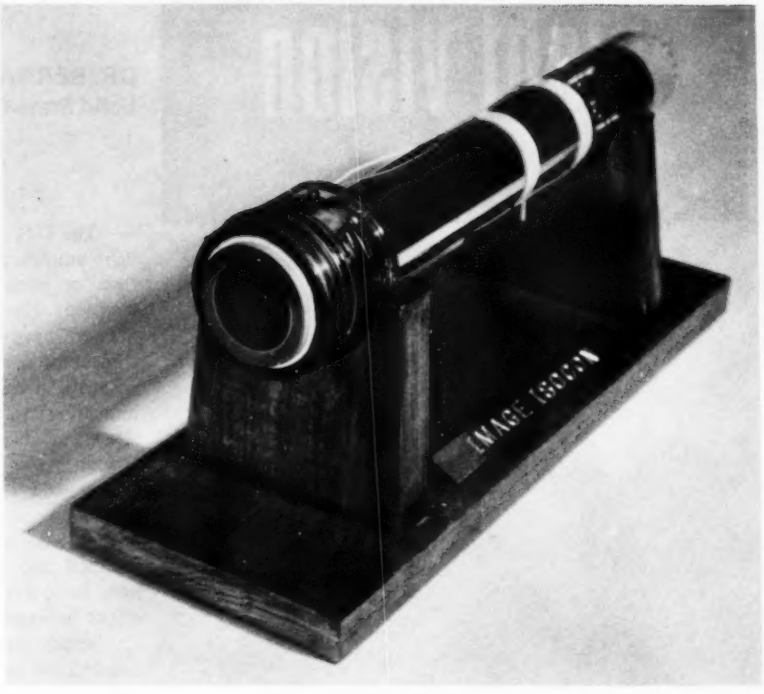

Figure 2. Image isocon tube.

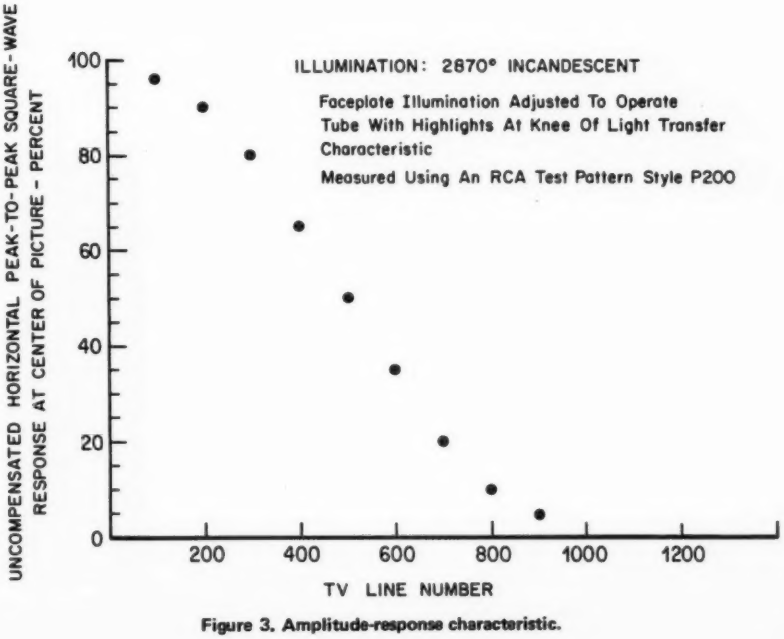

Figure 3. Amplitude-response characteristic.

night vision

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The U.S. Army has developed a very successful line of light amplifiers for nighttime operations. The light amplifiers or intensifiers consist of three stages fiberoptically coupled. The intensifiers, the "heart" of the "Starlight Scope," have recently been declassified and have been the subject of several lengthy publicity stories. ARL has been engaged in the application of the Starlight Scope and the intensifiers to various Air Force problems. One of the most significant has been the detection of the pilot's rescue beacon, type SDU-5E. This beacon is a compact xenon flasher and is part of every pilot's survival pack. Some modifications of the optical elements, especially for other devices associated with rescue operations, have been constructed and flight-tested. Results of these investigations have been instrumental in obtaining funding for a night-rescue helicopter avionics system.

Some special intensifiers have been designed and constructed under ARL sponsorship. Specifically, a three-stage S-1 system for near-infrared imaging has been developed. This system includes a thermoelectric cooler which greatly reduces the noise background of the S-1 photocathode. Figure 1 shows one of the units installed in an 0-2-type aircraft.

ARL maintains a continuing active interest and consulting role in the application of night-vision devices.

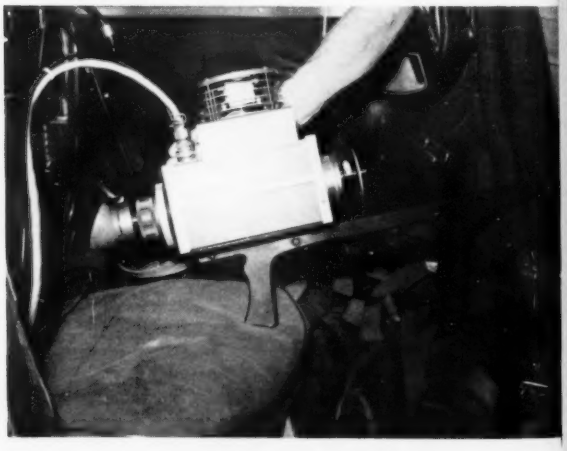

Figure 1. Thermoelectrically cooled S-1 system.

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